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THE WONDERS of SCIENCE IN MODERN LIFE

HENRY SMITH WILLIAMS

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THE WONDERS OF SCIENCE IN MODERN LIFE

V. 7

THE AMERICAN SUBMARINE BOAT "CUTTLEFISH" IN DRY DOCK AT THE BROOKLYN NAVY-YARD

THE WONDERS OF SCIENCE IN MODERN LIFE

BY

HENRY SMITH WILLIAMS, M.D., LL.D.

AND

EDWARD H. WILLIAMS, M.D.

IN

TEN

VOLUMES

—

ILLUSTRATED

Vol. VII

THE CONQUEST OF SEA AND LAND

FUNK & WAGNALLS COMPANY

NEW YORK AND LONDON

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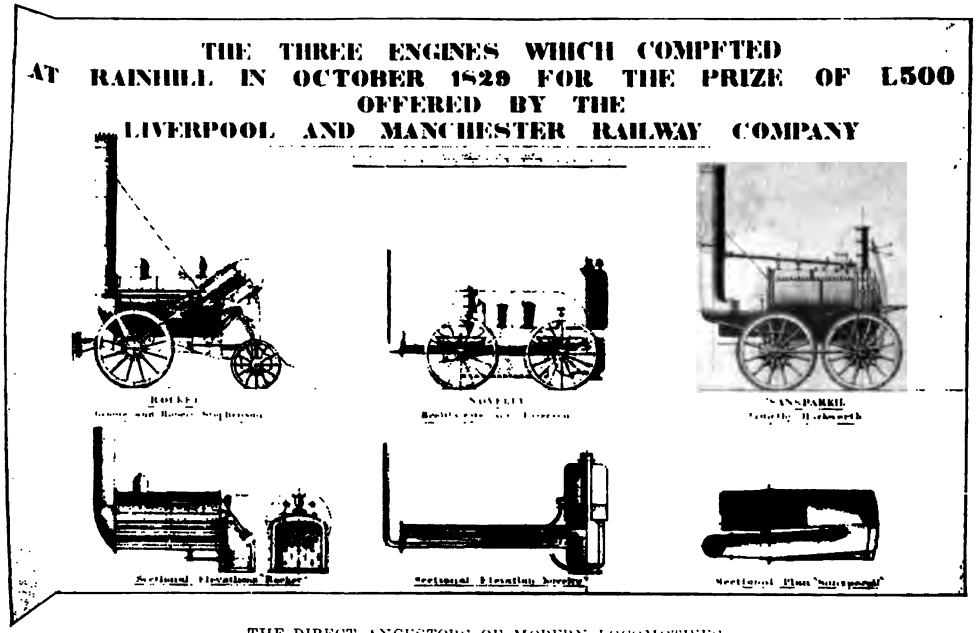
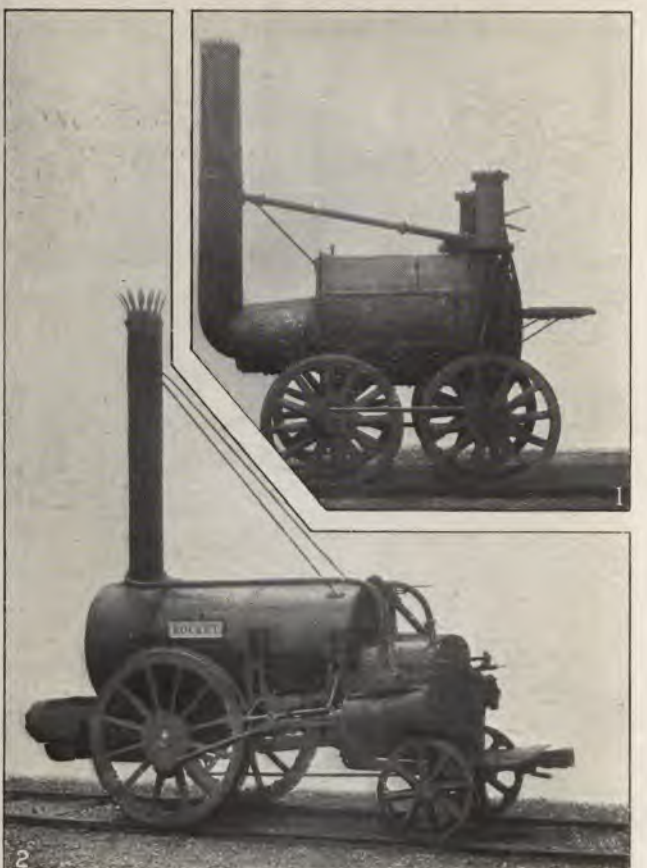
VOLUME VII

THE CONQUEST OF SEA AND LAND

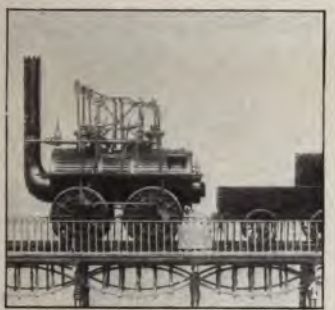


THE DIRECT ANCESTORS OF MODERN LOCOMOTIVES



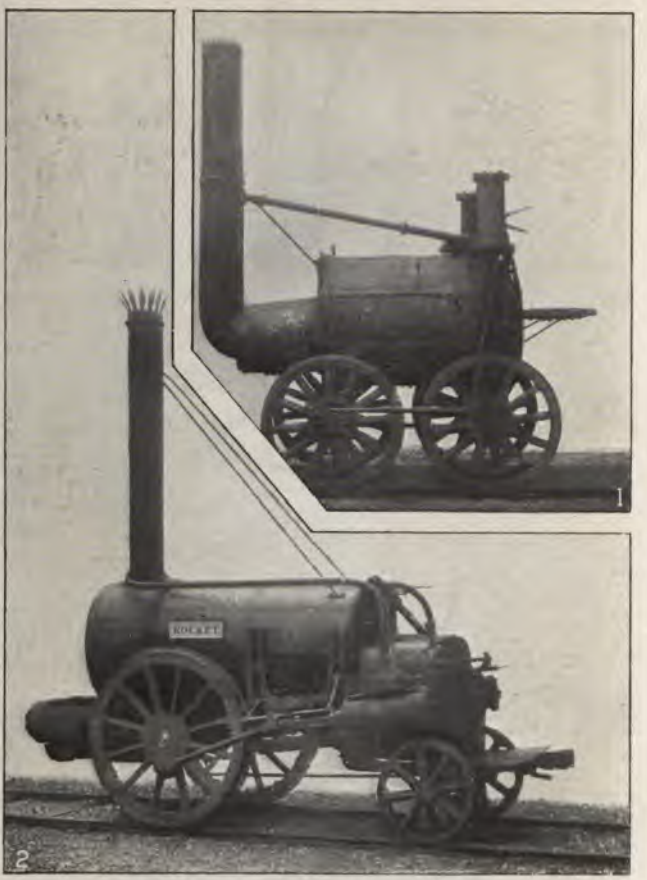
THE FAMOUS LOCOMOTIVES "ROCKET" AND "SANS-PAREIL"

Stevenson's celebrated *Rocket*, winner of the competition for *the prize of 500 pounds offered* in 1829 by the Directors of the Liverpool *and Manchester Railway*. The *Sans-pareil*, which, like the *Rocket, is still preserved* at the South Kensington Museum in *lon, competed unsuccessfully* for the prize.



A CENTURY'S PROGRESS IN LOCOMOTIVE BUILDING

Fig. 1—Model of locomotive engine No. 1 of the Stockton and Darlington Railway, England, built by Messrs. R. Stevenson & Company, *in 1825.* Fig. 2—The Blenkinsop locomotive, built in 1812-1 *to work on the* rack railway between Leeds and the Middleton c *liery, a distance of* 3.5 miles. Fig. 3—"Twentieth Century Limit *train of the* New York Central Railroad and a racing automo *Fig. 4—The locomotive Royal George,* which worked on the Sto *and Darlington* Railway, 1827-1842.



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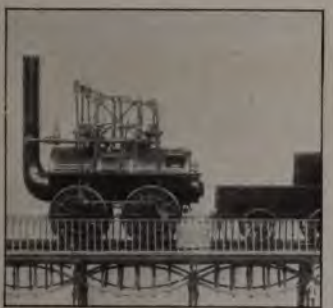

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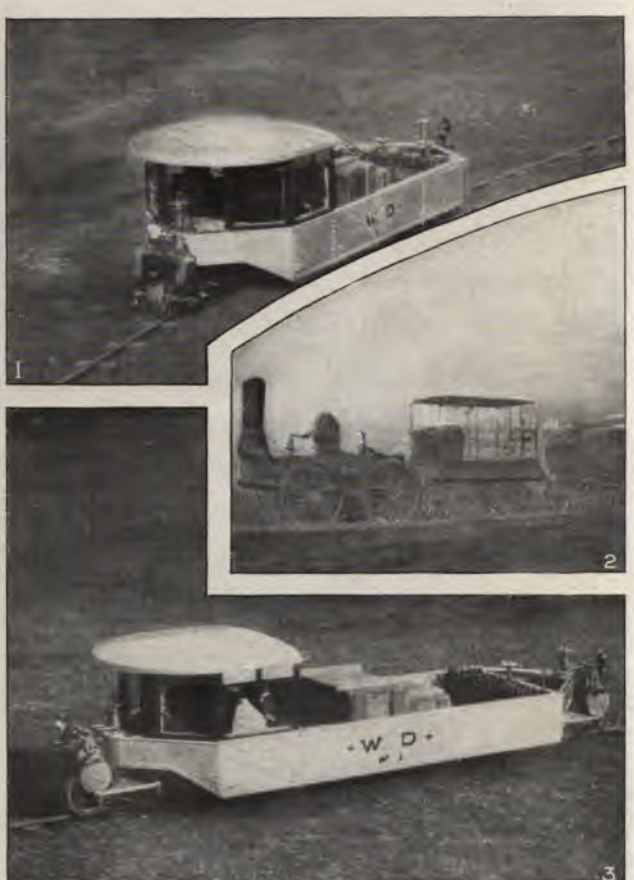
AN ENGLISH STEAM COACH OF 1827 AND A NEW YORK TAXICAB OF 1912

The steam coach constructed in 1827 by Sir Goldsworthy Gurney was the prototype of several others which entered upon regular and successful service between various English cities, and which are said to have maintained an average speed of about 12 miles an a maximum speed of a little over 20 miles an hour. It weighed about 2 tons and carried six inside and twelve outside *passengers.*



RETROSPECT AND PROSPECT IN TRANSPORTATION—THE DE WITT CLINTON TRAIN AND THE GYROCAR

The De Witt Clinton engine, with its archaic coaches, represents *the earliest type of* railway transportation in America. The Gyrocar, *two views of* which are given, is the working model of a single-*rail vehicle exhibited* in England by Mr. Louis Brennan in 1907.

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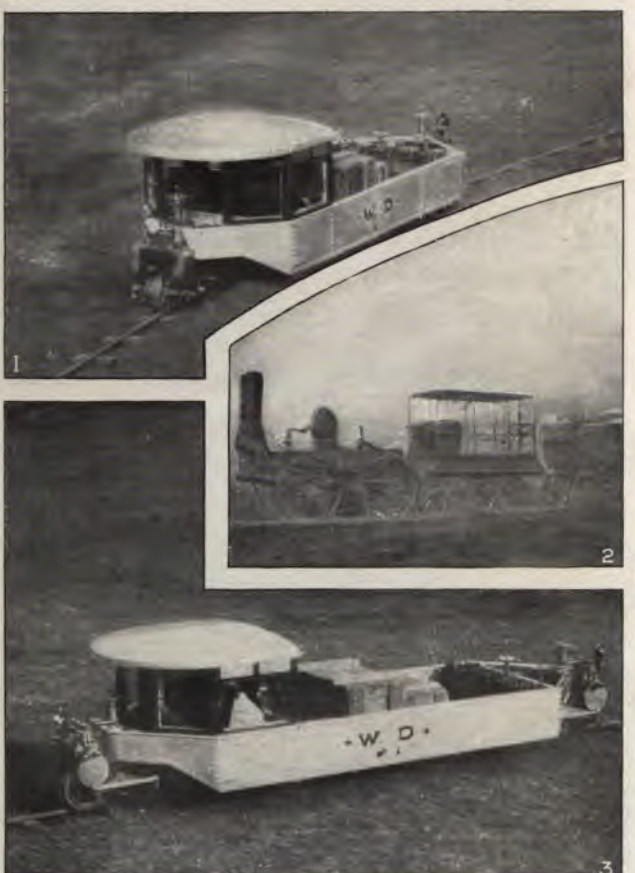

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THE SELANDIA

One of the first motor-driven ships in commission for ocean service

THE CONQUEST OF SEA AND LAND

I

THE CONQUEST OF THE ZONES

The contrast between modern and ancient times is strikingly suggested by reflection on the limited range of geographical knowledge of those Oriental and Classical nations who dominated the scene at that remote period which we are accustomed to characterize as the dawn of history. The Egyptians, peopling the narrow valley of the Nile, scarcely had direct dealings with any people more remote than the Babylonians and Assyrians occupying the valley of the Euphrates. Babylonians and Assyrians in turn were in touch with no Eastern civilization more remote than that of Persia and India, and knew nothing of any Western world beyond the borders of Greece. Greeks and Romans, when in succession they came to dominate the world stage,—developing a civilization which even as viewed from our modern vantage-ground seems marvelous,—were still confined to narrow strips of territory about the shores of the Mediterranean, and had but the vaguest notions as to any other regions of the earth.

In the later classical period, to be sure, the globe was subjected to wonderful measurements by Eratosthenes and by Posidonius, and the

fact that man's abiding place is a great ball utterly different from the world as conceived by the Oriental mind was definitely grasped and became more or less a matter of common knowledge. It was even conceived that there might be a second habitable zone on the opposite side of the equator from the region in which the Greeks and Romans found themselves, but as to just what this hypothetical region might be like, and as to what manner of beings might people it, even the most daring speculator made no attempt to decide. The more general view, indeed, precluded all thought of habitable regions lying beyond the confines of the Mediterranean civilization; conceiving rather that the world beyond was a mere waste of waters.

Doubtless the imaginative mind of the period must have chafed under these restrictions of geographical knowledge; and now and again a more daring navigator must have prest out beyond the limits of safety, into the Unknown, never to return. Once at least, even in the old Egyptian days, a band of navigators surpassing in daring all their predecessors, and their successors of the ensuing centuries, made bold to continue their explorations along the coast of Africa till they had passed to a region where—as Herodotus relates with wonder—the sun appeared "on their right hand," ultimately passing about the southern extremity of the African continent and completing the circumnavigation, returning with wonder tales to excite the envy, perhaps, but not the emulation of their fellows.

Then in due course some Phenician or Greek navigators coasted along the northern shores

beyond the "Pillars of Hercules" and discovered at the very confines of the world what we now term the British Isles. But this was the full extent of exploration throughout antiquity; and the spread of civilization about the borders of the known world was a slow and haphazard procedure during all those centuries that mark the Classical and Byzantine periods.

THE MARINER'S COMPASS

The change came with that revival of scientific learning which was to usher in the new era that we speak of as modern times. And here as always it was a practical mechanism that gave the stimulus to new endeavor. In this particular case the implement in question was the mariner's compass which consists, in its essentials, as every one is aware, of a magnetized needle floated or suspended in such a way that it is made under the influence of terrestrial magnetism to point to the north and south.

The mysterious property whereby the magnetized needle obeys this inscrutable impulse is, in the last analysis, inexplicable even to the science of our day. But the facts, in their crude relations, had been familiar from time immemorial to a nation whose habitat lay beyond the ken of the classical world—namely, the Chinese. It seems to be fairly established that navigators of that nation had used the magnetized needle, so arranged as to constitute a crude compass, from a period possibly antedating the Christian Era. To Western nations, however, the properties in the magnetized needle seem to have

been quite unknown—at least its possibilities of practical aid to the navigator were utterly unsuspected—until well into the Middle Ages. There is every reason to believe—tho absolute proof is lacking—that a knowledge of the compass came to the Western world from the Far East through the medium of the Arabs. The exact channel of this communication will perhaps always remain unknown. Nor have we any clear knowledge as to the exact time when the all-important information was transmitted. We only know that manuscripts of the twelfth century mentioned the magnetic needle as an implement familiar to navigators, and from this time forward, we may feel sure, the new possibilities of exploration made possible by the compass must have suggested themselves to some at least of the more imaginative minds of each generation. Indeed, there were explorers in each generation who pushed out a little into the unknown, as the discovery of various groups of islands in the Atlantic shows, altho the efforts of these pioneers have been eclipsed by the spectacular feat of Columbus.

The exact steps by which the crude compass of the Orientals was developed into the more elaborate and delicate instrument familiar to Western navigators can not be traced by the modern historian. It is known that sundry experiments were made as to the best form of needle, and in particular as to the best way of adjusting it on approximately frictionless bearings. But a high degree of perfection in this regard had been attained before the modern period; and the compass had been further per-

fected by attaching the needle to a circumferential card on which the "points of the compass," thirty-two in number, were permanently marked. At all events the compass card had been so divided before the close of the fourteenth century, as is proved by a chance reference by Chaucer. The utility of the instrument thus perfected—indeed its entire indispensableness—was doubtless by this time clearly recognized by all navigators; and one risks nothing in suggesting that without the compass no such hazardous voyage into the unknown as that of Columbus would ever have been attempted.

No doubt the earliest observers of the needle believed that it pointed directly to the north. If such were indeed the fact the entire science of navigation would be vastly simpler than it is. But it required no very acute powers of observation to discover that the magnetized needle does not in reality point directly toward the earth's poles. There are indeed places on the earth where it does so point, but in general it is observed to deviate by a few degrees from the exact line of the meridian. Such deviation is technically known as magnetic declination. That this declination is not the same for all places was discovered by Columbus in the course of his first transatlantic voyage.

A century or so later, the accumulated records made it clear that declination is not a fixt quantity even at any given place. An Englishman, Stephen Burrows, is credited with making the discovery that the needle thus shifts its direction slightly with the lapse of time, and the matter was more clearly determined a little

later by Gillebrand, Professor of Geometry at Graham College. Dr. Halley, the celebrated astronomer—whose achievements have been recalled to succeeding generations by the periodical return of the comet that bears his name—gave the matter attention, and in a paper before the Royal Society in 1692 he pointed out that the direction of the needle at London had changed in a little over a century (between 1580 and 1692) from 11 degrees 15 minutes east to 6 degrees west, or more than 17 degrees.

Halley conclusively showed that similar variations occurred at all other places where records had been kept. He had already demonstrated, a few years earlier, that the deviations of the compass noted at sea are not due to the varying attractions of neighboring bodies of land, but to some influence having to do with the problem of terrestrial magnetism in its larger aspects. Halley advocated the doctrine, which had first been put forward by William Gilbert, that the earth itself is a gigantic magnet, and that the action of the compass is dependent upon this terrestrial source and not, as many navigators believed, on the influence of a magnetic star, or on localized deposits of lodestone somewhere in the unknown regions of the north.

Further observations of the records presently made it clear that there are also annual and even daily variations of the compass of slight degree. The fact of diurnal variations was first discovered by Mr. Graham about the year 1719. More than half a century later it was observed by an astronomer named Wales, who was accompanying Captain Cook on his famous voyage

around the world (1772-74), that there is yet another fluctuation of the compass due to the influence of the ship on which it is placed. Considerable quantities of iron were of course used in the construction of wooden ships, and it was made clear that the ship itself comes under the influence of the earth's magnetism and exerts in turn an appreciable influence on the compass. The fluctuation due to this source is known as deviation, in contradistinction to the larger fluctuation already referred to as declination.

Not only is the deviation due to the ship's influence a matter of importance, but it was discovered by Captain Matthew Flinders, in the course of his explorations along the coast of New Holland in the year 1801-02, that the influence of the ship over its compass varies with the direction of the ship's prow.

Needless to say, the problem of the deviation of the compass due to the influence of the ship is enormously complicated when the ship, instead of being constructed chiefly of wood, is made of iron or steel. It then becomes absolutely essential that the influence of vessels shall be reckoned with and so far as possible compensated. Such compensation may be effected by the adjustment of bodies of iron, as first suggested by Barlow, or by the use of permanent magnets, as first attempted by England's Astronomer Royal, Professor Airy. At the very best, however, it is never possible totally to overcome the ship's perverting influence, allowance for which must be made if an absolutely accurate conclusion is to be drawn from the record presented by the compass.

Early in the twentieth century an American ship, christened the *Carnegie,* in honor of the philanthropist who supplied funds for the enterprise, was constructed for the express purpose of making accurate charts of the lines of magnetic declination in various parts of the globe. This ship differs from every other vessel of considerable size ever hitherto constructed in that no magnetic material of any kind was used in connection with its structure or equipment. For the most part iron was substituted by copper or other non-magnetic metal. Pins of locust-wood largely took the place of nails; and wherever it was not feasible to do away with iron altogether it was used in the form of non-magnetic manganese steel. The purpose of the *Carnegie* is to provide accurate charts of magnetic declination for the use of navigators in general. The value of observations made with this non-magnetic ship will be clear when it is reflected that with an ordinary ship the observer can never be absolutely certain as to what precise share of the observed fluctuation of the compass is due at any given moment to the ship's influence. In other words—using technical terminology—he can never apportion with absolute accuracy the influence of declination and of deviation. Yet it is highly important that he should be able to do so, inasmuch as the declination of the compass is an all-important element in reckoning the exact location of the ship, and would be the same for every ship at that place, whereas deviation denotes a purely local disturbance which would never be the same for any two ships of different construction.

Not only does the magnetized needle thus tend to vary in the direction of its horiontal action, but it also tends when suspended at the middle to shift its vertical axis. In regions near the equator, indeed, the magnetized needle maintains a horizontal position, but if carried into northern or southern latitudes it progressively "dips," its polar end sinking lower and lower. This dipping of the needle seems to have been first observed by Robert Norman, an English nautical instrument maker about the year 1590. It was brought to the attention of Gilbert and carefully tested by him in the course of his famous pioneer experiments. Gilbert was led to predicate the existence of magnetic poles, the exact location of which would be indicated by the dipping needle, which, sinking lower and lower as northern latitudes were attained, would ultimately at the magnetic pole itself assume a vertical direction.

That this is a correct expression of the facts was determined in the year 1831 by Sir James Ross, who in the course of his Arctic explorations observed the vertical dip and so located the northern magnetic pole at about 70 degrees 5 minutes north latitude and 96 degrees 43 minutes west longitude. It was thus proved that the magnetic pole is situated a long distance —more than 1,200 miles—from the geographical pole. The location of the south magnetic pole was most accurately determined in 1909 by Lieutenant Shackleton's expedition at about 73 degrees south latitude and 156 degrees east longitude. The two magnetic poles are thus not directly opposite each other on the earth's surface, and the magnetic axis of the earth does

not coincide with the geographical center of the globe itself.

From the standpoint of practical navigation the dip of the needle is a matter of much less significance than its horizontal fluctuations. Robert Norman himself attempted to overcome the dip by a balancing apparatus applied to the needle; and the modern compass is suspended in such a way that the propensity to dip does not interfere with the lateral movements which supply the navigator with all important information. The modern compass in question is the invention of Lord Kelvin and was patented by him in 1876. It consists of a number of small magnets arranged in parallel and held in position by silk threads, each suspended, cobweb-like, from the circular rim of aluminum. The weight—which in the aggregate is relatively slight—being thus largely at the circumference, the instrument has a maximum period of oscillation and hence a high degree of stability. Its fluctuations due to the ship's influence are corrected by a carefully adjusted disposition of metal balls and magnets.

SAILING BY DEAD RECKONING

While the compass gives indispensable information as to direction, and is constantly under the eye of the pilot, it of course can give no direct information as to the distance traversed by the ship, and hence does not by itself suffice to tell the navigator his whereabouts. In the early days there was indeed an expectation that the observed declination of the compass would re-

veal to the navigator his longitude and that the observation of the dip might enable him to determine his latitude. But more extended observation shows that this was asking altogether too much of the compass, and while it may be useful as an accessory it is by no means the navigator's chief reliance in determining his location. This is accomplished, as every one is aware, in clear weather by the observation of the heavenly bodies. In cloudy weather, however, such observations obviously can not be made, and the seaman must direct his ship and estimate his location—an all-important matter when he is approaching the coast—by what is called dead reckoning. One element of this reckoning is furnished by the compass, inasmuch as that is his sole guide in determining the direction of the ship's progress. The other element is supplied by the log which furnishes him a clue as to the distance traversed hour by hour.

It is rather startling to reflect that the navigators of the Middle Ages had no means whatever of determining the rate of progress of a ship at sea, beyond the crudest guesses unaided by instrument of any kind. When Columbus made his voyage he had no means of knowing what distance he had actually sailed; nor was any method of measuring the ship's speed utilized throughout the course of the ensuing century. In the year 1570, however, one Humfray Cole suggested a theoretical means of measuring the ship's rate of progress by means of an object dropt back of the ship and allowed to drag through the water; and this suggestion led a generation later to the introduction of the log,

which was first actually tested, so far as can be learned, in the year 1607.

The original log was so called because it consisted essentially of an actual log or piece of wood. To the center of this a string was attached, and in testing the ship's rate of progress this string was allowed to slip through the fingers of a sailor who counted the number of knots—placed, of course, at regular intervals on the string—that passed through his fingers in a given time. As the log itself would remain practically stationary in the water where it was dropt, the number of knots counted indicated the distances traversed by the ship in a given time. In practise the time was usually gaged by a half-minute sand-glass, and the knots were arranged at such a distance on the cord that, in the course of the half-minute, one knot would pass through the fingers for each nautical mile covered by the ship in an hour. The actual distance between the knots was therefore about fifty feet. The nautical or geographical mile represents one degree of the earth's circumference at the equator, amounting therefore to 6,008 feet, as against the 5,280 feet of the statute mile. It was the use of the log-line with its knots, as just explained, that led to the dubbing of the nautical mile by the name "knot," which is still familiarly employed, tho the knotted log-line itself has been superseded in recent times, except on very old-fashioned sailing ships.

The log retains its place even in the most modern ship, tho its form is materially altered, and its importance is somewhat lessened owing to the fact that the experienced skipper can

test the speed of his ship very accurately by noting the number of revolutions per minute of the ship's propellers. It is indeed the ship's propeller that supplies the model for the modern log, in which the primitive piece of wood is replaced by a torpedo-like piece of metal with miniature propeller-like blades at its extremity. This apparatus is towed at the end of a long line, and its blades, whirling more or less rapidly according to the speed of the ship, communicate their motion to a recording apparatus, adjusted at the ship's stern, to which the line is attached and the face of which ordinarily presents a dial on which the speed of the ship may be observed as readily as one observes the time by the clock.

Some recent modifications of the log employ an electrical device to register the progress, but the principle of the revolving vanes, which owe their speed to the rate at which they are dragged through the water, is the fundamental one upon which the action of the log usually depends, tho attempts have been made to substitute pressure-gage systems.

While the modern log records the speed of the ship with a fair degree of accuracy, its register shows at best only an approximation of the facts. As already mentioned the rate of revolution of the ship's propeller blades furnishes what most navigators regard as a rather more dependable test of speed. An apparatus for recording this is found on the bridge of the modern ship. But due allowance must of course be made for the effect of winds, waves, and ocean currents. These constantly variable factors obviously make the estimate as to the precise

distance traversed by a ship in a given time a matter not altogether devoid of guesswork; and no navigator who has been obliged to sail for several days by dead reckoning approaches a coast with quite the same degree of satisfaction that he may entertain if his log has been checked by observation of the sun or stars. In case, however, a navigator is able to check his reckoning by astronomical observations, aided by the chronometer, he determines his location with great accuracy.

THE DEVELOPMENT OF THE SEXTANT

The instrument with which such astronomical observations are made is known as the sextant. Its purpose is to measure with great accuracy the angle between two objects, which in practise are the horizon line on one hand and some celestial body, usually the sun, on the other. The determination of the latitude of the ship, for example, is a matter of comparative ease, if the sun chances to be unobscured just at midday. The navigator has merely to measure the exact elevation of the sun as it crosses the meridan,—that is to say, when it is at its highest point,—and, having made certain corrections for so-called dip and refraction, to which we shall refer more at length in a moment, a very simple calculation reveals the latitude—that is to say, the distance from the terrestrial equator.

That the latitude of a ship could thus be determined, with greater or less accuracy, has been familiar knowledge to seamen from a very early period. It was by the use of this principle that

the earth was measured by Eratosthenes and Posidonius in classical times and the sailors of antiquity probably carried with them a crude apparatus for measuring the height of sun and stars, as the medieval navigators are known to have done.

The simplest and crudest form of measurer of which the record has been preserved is known as the cross-staff. This consisted essentially of a stick about a yard in length called the staff, on which a crosspiece was arranged at right angles, so adjusted at the center as to slide back and forth on the staff. An eyepiece at one end of the staff was utilized to sight along projections at either end of the crosspiece. If the apparatus is held so that one of the lines of sight is directed to the horizon, and then the crosspiece slid along the staff until the other line of sight is directed toward the sun or a given star, the angle between the two lines of sight will obviously represent the angle of altitude of the celestial body in question. But the difficulty of using an apparatus which requires two successive observations to be made without shift of position is obvious, and it is clear that the information derived from the cross-staff must have been at best very vague—by no means such as would satisfy the modern navigator.

Even the navigators of the fifteenth century were aware of the deficiencies of the cross-staff and sought to improve upon it. The physicians of Henry the Navigator of Portugal, Roderick and Joseph by name, and another of his advisers, Martin de Bohemia, are credited with inventing, or at least introducing, a much

improved apparatus known as the astrolabe. This consists of a circle of metal, arranged to be suspended from a ring at the side, so that one of its diameters would maintain the horizontal position through the effect of gravity. A superior quadrant of the circle was marked with degrees and minutes. A straight piece of metal, with sights so that it could be accurately pointed, was adjusted to revolve on a pivot at the center of the circle. This sighting piece being aimed at the sun, for example, the elevation of that body could be read directly on the measuring arc of the circle. Here, then, was no new principle involved, but the instrument had obvious points of advantage over the cross-staff, in particular because only a single sight need be taken, the horizon line being determined, as already explained, through the action of gravitation.

The astrolabe did not gain immediate favor with practical navigators, and it was at best a rather clumsy instrument, subject to peculiar difficulties when used on a rolling ship. Many attempts were made to improve upon it, but for a long time none of these was altogether successful. The final suggestion as to means of overcoming the difficulties encountered in measuring the altitude of astronomical bodies was made by Sir Isaac Newton. But nothing practical came of his discovery, as it was not published until a long time after his death. Meantime independent discovery of the same principle was made by Thomas Godfrey, of Philadelphia, in 1730, and by the English astronomer, Hadley, who published his discovery before the Royal

Society in 1731. The instrument which Hadley devised was called a quadrant. The principle on which it worked involved nothing more complex than the use of two mirrors, one of them (known as the horizon glass and having only half its surface mirrored) fixt in the line of vision of a small telescope; the other (called the index mirror) movable with the arm of an indicator, which is so adjusted as to revolve about the axis of the quadrant. In operation these two mirrors enable the images of two objects, the distance between which is to be measured, to be superimposed. The telescope may be pointed at the horizon, for example, directly under the position of the sun, and the arm of the instrument, altering the position of the so-called index mirror, may be rotated until the limb of the sun seems just to touch the horizon—the latter being viewed through the unsilvered half of the horizon glass. The scale at the circumference of the instrument is marked in half-degrees, which, however, are registered as whole degreees, and which, so interpreted, give the direct measurement of the angular distance between the horizon and the sun; in other words, the measurement of the sun's altitude or so-called declination.

The instrument just described, perfected as to details but not modified as to principles, constitutes the modern sextant, which is used by every navigator, and which constitutes, along with the compass and chronometer, the practical instrumental equipment that enables the seaman to determine—by using the tables of the *Nautical Almanac*—his exact position on the earth's sur-

face from observation of the sun or certain of the fixt stars. The modern instrument is called a sextant because it has, for convenience sake, been restricted in size to about one-sixth of a circle instead of the original one-quarter, the small size being found to answer every practical purpose, since it measures all angles up to 120 degrees.

In practise the sextant is an instrument only six or eight inches in diameter. It is held in the right hand and the movable radial arm is adjusted with the left hand with the aid of a micrometer screw and the reading of the scale is made accurate by the vernier arrangement. The ordinary observation—which every traveler has seen a navigator make from the ship's bridge just at midday—is carried out by holding the sextant in a vertical position directly in line of the sun, and sighting the visible horizon line, meantime adjusting the recording apparatus so as to keep the sun's limb seemingly in touch with the horizon. As the sun is constantly shifting its position the vernier must be constantly adjusted until the observation shows that the sun is at the very highest point. The instrument being clamped and the scale read, the latitude may be known when proper correction has been made for the so-called dip, for refraction, and where great accuracy is required, for parallax.

Dip, it may be explained, is due to the fact that the observation is made not from the surface of the water but from an elevation, which is greater or less according to the height of the bridge, and which therefore varies with each individual ship. The error of refraction is due

to the refraction of the sun's light in passing through the earth's atmosphere, and will vary with the temperature and the degree of atmospheric humidity, both of which conditions must be taken into account. The amount of refractive error is very great if an object lies near the horizon. Every one is familiar with the oval appearance of the rising or setting sun, which is due to refraction. With the sun at the meridian, the refractive error is comparatively slight; and when a star is observed at the zenith the refractive error disappears altogether.

By parallax, as here employed, is meant the error due to the difference in the apparent position of the sun as viewed by an observer at any point of the earth's surface from what the apparent position would be if viewed from the line of the center of the earth from which theoretical point the observations are supposed to be made. In the case of bodies so distant as the sun, this angle is an exceedingly minute one, and in the case of the fixt stars it disappears altogether. The sun's parallax is very material indeed from the standpoint of delicate astronomical observations, but it may be ignored altogether by the practical navigator in all ordinary observations. There is one other correction that he must make, however, in case of sun observations; he must add, namely, the amount of the semi-diameter of the sun to his observed measurement, as all calculations recorded in the *National Almanac* refer to the center of the sun's disk.

PERFECTING THE CHRONOMETER

The observation of the sun's height, with the various corrections just suggested, suffices by itself to define the latitude of the observer. Something more is required, however, before he can know his longitude. How to determine this, was a problem that long taxed the ingenuity of the astronomer. The solution came finally through the invention of the chronometer, which is in effect an exceedingly accurate watch.

Time measurers of various types have, of course, been employed from the earliest times. The ancient Oriental and Classical nations employed the so-called clepsydra, which consisted essentially of receptacles from or into which water dript through a small aperture, the lapse of time being measured by the quantity of water. At an undetermined later date sand was substituted for the water, and the hour-glass with which, in some of its forms, nearly every one is familiar, came into use. For a long time this remained the most accurate of time measurers, tho efforts were early made to find substitutes of greater convenience. Then clocks operated by weights and pulleys were introduced; and, finally, after the time of the Dutchman Huygens, the pendulum-clock furnished a timepiece of great reliability. But the mechanism operated by weight or pendulum is obviously ill-adapted to use on shipboard. Portable watches, in which coiled springs took the place of the pendulum, had indeed been introduced, but the mechanical ingenuity of the watchmaker could not suffice to produce very dependable timekeepers. The very

idea of a watch that would keep time accurately enough to be depended upon for astronomical observations intended to determine longitude was considered chimerical.

Nevertheless the desirability of producing a portable timekeeper of great accuracy was obvious, and the efforts of a large number of experimenters were directed toward this end in the course of the eighteenth century. These efforts were stimulated by the hope of earning a prize of twenty thousand pounds offered by the British Government for a watch sufficiently accurate to determine the location of a ship with maximum error of half a degree or thirty nautical miles, corresponding to two minutes of time, in the course of a transatlantic voyage. It affords a striking illustration of the relative backwardness of nautical science, and of the difficulties to be overcome, to reflect that no means then available enabled the navigator at the termination of a transatlantic voyage to be sure of his location within the distance of thirty nautical miles by any means of astronomical or other observation known to the science of the time.

The problem was finally solved by an ingenious British carpenter named John Harrison, who devoted his life to the undertaking, and who came finally to be the most successful of watchmakers. Harrison first achieved distinction by inventing the compensating pendulum—a pendulum made of two metals having a different rate of expansion under the influence of heat, so adjusted that change in one was compensated by a different rate of change in the other. Up to the time of this discovery, even the best of pendulum

clocks had failed of an ideal degree of accuracy owing to the liability to change of length of the pendulum—and so, of course, to corresponding change in the rate of its oscillation—with every alteration of temperature. Another means of effecting the desired compensation was subsequently devised by Mr. Graham, through the use of a well of mercury in connection with the pendulum, so arranged that the expansion of the mercury upward in its tube would compensate the lengthening of the pendulum itself under effect of heat, and vice versa; but the Harrison pendulum, variously modified in design, remains in use as a highly satisfactory solution of the problem.

Harrison early conceived the idea that it might be possible to apply the same principle to the balance-wheel of the watch. This problem presented very great practical difficulties, but by persistent effort these were finally overcome, and a balance-wheel produced, which, owing to the unequal expansion and contraction of its two component metals under changing temperature, altered its shape and so maintained its rate of oscillation almost—tho never quite—regardless of changing conditions of temperature.

In 1761 Harrison produced a watch which was tested on a British ship in a trip to the West Indies in that and the succeeding year, and which proved to be a timekeeper of hitherto unexampled accuracy. The inventor had calculated that the watch, when carried into the tropics, would vary its speed by one second per day with each average rise of ten degrees of -ature. Making allowance for this pre- alteration it was found that the watch was

far within the limits of variation allowed by the conditions of the test above outlined. It had varied indeed only five seconds during the journey across the ocean. On the return trip the watch was kept in a place near the stern of the ship, for the sake of dryness, where, however, it was subjected to a great deal of joggling, which led to a considerably greater irregularity of action; but even so its variation on reaching British shores was such as to cause a maximum miscalculation of considerably less than thirty nautical miles.

Altho Harrison seemed clearly enough to have won the prize, there were influences at work that interfered for a time with full recognition of his accomplishment. Presently he received half the sum, however, and ultimately, after having divulged the secret of his compensating balance and proved that he could make other watches of corresponding accuracy, he received the full award.

Minor improvements have naturally been made in the watch since that time, but the essential problem of making a really reliable portable timepiece was solved by the compensating balance-wheel of Harrison. The ship's chronometer of today is merely a large watch, with an escapement of particular construction, mounted on gimbals so that it will maintain a practically horizontal position.

Modern ships are ordinarily provided with at least three of these timekeepers in order that each may be compared with the others, and a more accurate determination of the time made than would be possible from observation of a single

instrument; inasmuch as no absolutely accurate timekeeper has ever been constructed. Two chronometers would obviously be not much better than one, since there would be no guide as to whether any variation between them had been caused by one running too fast or the other too slowly. But with a third chronometer to check the comparison, it is equally obvious that a dependable clue will be given as to the exact time.

It is to be understood of course that the variation of any of the chronometers will be but slight if they are good instruments. Moreover the tendency to vary in one direction or the other of each individual instrument will be known from previous tests. Such tests are constantly made at the Royal Observatory in England and elsewhere, and the best chronometers bear certificates as to their accuracy and as to their rate of variation. It may be added that a chronometer or other timepiece is technically said to be a perfect instrument, not when it has no variation at all —since this has proved an unattainable ideal— but when its variation is slight, is always in one direction, and is perfectly or almost perfectly uniform.

FINDING THE TIME WITHOUT A CHRONOMETER

In the reference made above to the testing of Harrison's watch, it was stated that that instrument varied by only a certain number of seconds in the course of the westerly voyage across the Atlantic, and that its variation was somewhat greater on the return voyage. This implies, clearly, that some method was available to test the

watch in the West Indies, without waiting for the return to England. At first thought this may cause no surprize, since the local time can of course be known anywhere through meridian observations; but on reflection it may seem less and less obvious as to just what test was available through which the exact difference in time between Greenwich, at which the watch was originally tested, and local time at the station in the West Indies could be determined. There are, however, several astronomical observations through which this could be accomplished, and in point of fact the comparative times and hence the precise longitudes at many points on the Western Hemisphere—and indeed of all portions of the civilized globe—were accurately known before the day of the chronometer.

One of the simplest and most direct means of testing the time of a place, as compared with Greenwich time, is furnished by observation of the occultation of one of the moons of Jupiter. By occultation is meant, as is well known, the eclipse of the body through passing into the shadow of its parent planet. This phenomenon, causing the sudden blotting out of the satellite as viewed from the earth, occurs at definite and calculable periods and is obviously quite independent of any terrestrial influence. It occurs at a given instant of time and would be observed at that instant by any mundane witness to whom Jupiter was at that time visible. If then an observer noted the exact local time at which occultation occurred, and compared this observed time with the Greenwich time at which such occultation was predicted to occur, as re-

corded in astronomical tables, a simple subtraction or addition will tell him the difference in time between his station and the meridian at Greenwich; and this difference of time can be translated into degrees of longitude by merely reckoning fifteen degrees for each hour of time, and fractions of the hour in that proportion.

It will be noted that this observation has value for the purpose in question only in conjunction with certain tables in which the movements of Jupiter and its satellite are calculated in advance. This is equally true of the various other observations through which the same information may be obtained—as for example, the observation of a transit of Mars, or the measurement of apparent distance between the moon and a given fixt star. Before the tables giving such computations were published it was quite impossible to determine the exact longitude of any transatlantic place whatsoever. We have already pointed out that Columbus had only a vague notion as to how far he had sailed when he discovered land in the West. The same vagueness obtained with all the explorations of the immediately ensuing generations.

It was not until about the middle of the sixteenth century that Mercator and his successors brought the art of map-making to perfection; and the celebrated astronomical tables of the German Mayer, which served as the foundation for calculations of great importance to the navigator, were not published until 1753. The first *Nautical Almanac*, in which astronomical tables to guide the navigator were included, was published at the British Royal Observatory in 1767.

At the present time, a navigator would be as likely to start on a voyage without compass and sextant as without charts and a *Nautical Almanac*. Indeed, were he to overlook the latter the former would serve but a vague and inadequate purpose. Yet, as just indicated, this invaluable adjunct to the equipment of the navigator was not available until well toward the close of the eighteenth century. But of course numerous general tables had been in use long before this, else —to revert to the matter directly in hand—it would not have been possible to make the above-recorded test in the case of Harrison's famous watch in the voyage of 1761-62.

ASCERTAINING THE SHIP'S LONGITUDE

In the days before the chronometer was perfected, almost numberless methods of attempting to determine the longitude of a ship at sea were suggested. There were astronomers who advocated observation of the eclipse of Jupiter's satellites; others who championed the method of so-called lunars—that is to say, calculation based on observation of the distance of the moon at a given local time from one or another of certain fixt stars arbitrarily selected by the calculator. Inasmuch as the seaman could always regulate even a faulty watch from day to day by observation of the meridian passage of the sun, it was thought that these observations of Jupiter's satellite or of the moon would serve to determine Greenwich time and therefore the longitude at which the observation was made with a fair degree of accuracy. But in practise it is not

easy to observe the eclipse of Jupiter's satellite without a fair telescope; and it was soon found that the tables for calculating the course of the moon were by no means reliable, hence theoretically excellent methods of determining longitude by observation of that body proved quite unreliable in practise.

It was with the chief aim of bettering our knowledge of the moon's course through long series of very accurate observations that the Royal Observatory at Greenwich was founded. Perhaps it was not unnatural under these circumstances that certain of the Astronomers Royal should have advocated the method of lunars as the mainstay of the navigator. In particular Maskelyne, who was in charge of the Observatory in the latter part of the eighteenth century, was so convinced of the rationality of this method that he was led to discredit the achievements of Harrison's watches, and for a long time to exert an antagonistic influence, which the watchmaker resented bitterly and it would appear not without some show of reason.

Ultimately, however, the accuracy of the watch, and [illegible]s indispensableness in the perfected form of [illegible] chronometer, having been fully demonstrated, the method of lunars became practically [illegible]ought and the mariner was able to determine [illegible]ngitude with the aid of sextant, chronometer, and *Nautical Almanac,* by means of direct observation of the altitude of the sun by day and of sundry fixt stars by night, a much simpler calculation sufficing than was required by the older method.

As the sun is the chief time-measurer, whose

rate of passage in a seeming circumnavigation of the heavens is recorded by the dial of clock, watch, or chronometer, it would seem as if the simplest possible method of determining longitude would be found through observation of the sun's meridian passage. The user of the sextant on shipboard always makes, if weather permits, a meridian observation of the sun, and such observation gives him an accurate gage of the altitude of the sun at its highest point and hence of his own latitude. By adjusting the arm of the sextant with which this observation is made, the observer is able to determine the exact point reached by the sun in its upward course with all requisite accuracy.

But, unfortunately for his purpose, the sun does not poise for an instant at the apex of its upward flight and then begin its descent. On the contrary, its orbit being circular, the course of the sun just at its highest point is approximately horizontal for an appreciable length of time, and while the observer therefore has adequate opportunity to measure with accuracy the highest point reached, he can not possibly make sure, within the limits of a considerable fraction of a minute, as to the precise moment when the center of the sun is on the meridian. He can, indeed, determine this with sufficient accuracy for rough calculations, but modern navigation demands something more than rough calculations, inasmuch as a variation in time of one minute represents one-quarter of a degree of longitude, or fifteen nautical miles at the equator, and such uncertainty as this would imply can by no means be permitted in

the safe navigation of a ship that may be passing through the water at the rate of a nautical mile in less than three minutes.

It follows that meridian observation of the sun, owing to the necessary inaccuracy of such observation, is not the ideal method. In point of fact the sun may be observed for this purpose to much better advantage when it is at a considerable distance from the meridian, since then its altitude above the horizon at a given moment is the only point necessary to be determined. The calculation by which the altitude of the sun may be translated into longitude is indeed more complicated in this case; but while spherical trigonometry is involved in the calculation, the tables supplied by the *Nautical Almanac* enable the navigator to make the estimate without the use of any knowledge beyond that of the simplest mathematics.

MEASURING A DEGREE OF LATITUDE

While these observations tell the navigator his exact location in degrees of latitude and longitude, such knowledge does not of course reveal the distance traversed unless the precise length of the degree itself is known; and this obviously depends upon the size of the earth. Now we have seen that the earth was measured at a very early date by Greek and Roman astronomers, but of course their measurements, remarkable tho they were considering the conditions under which they were made, were but rough approximations of the truth. Numerous attempts were made to improve upon these early measure-

ments, but it was not until well into the seventeenth century that a really accurate measurement was made between two points on the earth's surface, the difference between which, as measured in degrees and minutes, was accurately known.

In June of the year 1633, the Englishman, Robert Norman, made very accurate observations of the altitude of the sun on the day of the summer solstice (when of course it is at its highest point in the heavens); the observation being made with a quadrant several feet in diameter stationed at a point near the Tower of London. On the corresponding day of the following year he made similar observations at a point something like 125 miles south of London, in Surrey. The two observations determined the exact difference in latitude between the two points in question.

Norman then undertook a laborious survey, that he might accurately measure the precise distance in miles and fractions thereof that corresponded to these known degrees of latitude. He made actual measurements with the chain for the most part, but in a few places where the topography offered peculiar difficulties he was obliged to depend upon the primitive method of pacing.

The modern surveyor, equipped with instruments for the accurate measuring of angles, not differing largely in principle from the quadrant of the navigator, would consider Norman's method of measurement a very clumsy one. He would measure only a single original base line of any convenient length, but would make that measure-

ment with very great accuracy, using, perhaps, a rod packed in ice that it might not vary in length by even the fraction of an inch through changes in temperature. An accurate base line thus secured, he would depend thereafter on the familiar method of triangulation, in which angles are measured very accurately, and from such measurement the length of the sides of the successive triangles determined by simple calculation. In the end he would thus have made the most accurate determination of the distance involved, without having actually measured any portion thereof except the original base line. Notwithstanding the crudity of Norman's method, however, his estimate of the actual length of a degree of the earth's surface was correct, as more recent measurements have demonstrated, within twelve yards—a really remarkable result when it is recalled that the total length of the degree is about sixty nautical miles.

Inasmuch as the earth is not precisely spherical, but is slightly flattened at the poles, successive degrees of latitude are not absolutely uniform all along a meridan, but increase slightly as the poles are approached. The deviation is so slight, however, that for practical purposes the degree of latitude may be considered as an unvarying unit. But obviously such is not the case with a degree of longitude. The most casual glance at a globe on which the meridian lines are drawn shows that these lines intersect at the poles, and that the distance between them is, in the nature of the ease, different at each successive point between poles and equator. It is only at the equator itself that a degree of

longtitude represents $\frac{1}{360}$ of the earth's circumference. Everywhere else the parallels of latitude cut the meridians in what are termed small circles—that is to say, circles that do not represent circumference lines in the plane of the earth's center. Therefore, while all points on any given meridian of longitude are equally distant in terms of degrees and minutes of arc from the meridian of Greenwich, the actual distances from that meridian of the different points as measured in miles will depend entirely upon their latitude.

At the equator each degree of longitude corresponds to (approximately) sixty miles, but in the middle latitudes traversed for example by the transatlantic lines, a degree of longitude represents only half that distance; and in the far North the meridians of longitude draw closer and closer together until they finally converge, and at the poles all longitudes are one.

It follows, then, that the navigator must always know both his latitude and his longitude in order to estimate the exact distance he has sailed. We have seen that a single instrument, the sextant, enables him to make the observations from which both these essentials can be determined. We must now make further inquiry as to the all-important guide without the aid of which his observations, however accurately made, would avail him little. This guide, as already pointed out, is found in the set of tables known as the *Nautical Almanac.*

THE NAUTICAL ALMANAC

Had the earth chanced to be poised in space with its axis exactly at right angles to its plane of revolution, many computations of the astronomer would be greatly simplified. Again, were the planetary course circular instead of elliptical, and were the earth subject to no gravitational influences except that of the sun and moon, matters of astronomical computation would be quite different from what they are. But as the case stands, the axis of the earth is not only tipped at an angle of about twenty-five degrees, but is subject to sundry variations, due to the wabbling of the great top as it whirls.

Then the other planets, notably the massive Jupiter, exert a perverting influence which constantly interferes with the regular progression of the earth in its annual tour about the sun. A moment's reflection makes it clear that the gravitation pull of Jupiter is exerted sometimes in opposition to that of the sun, whereas at other times it is applied in aid of the sun, and yet again at various angles. In short, on no two successive days—for that matter no two successive hours or minutes—is the perturbing influence of Jupiter precisely the same.

What applies to the earth applies also, of course, to the varying action of Jupiter on the moon and to the incessantly varied action of the moon itself upon the earth. All in all, then, the course of our globe is by no means a stable and uniform one; tho it should be understood that the perturbations are at most very slight indeed as compared with the major motions that

constitute its regular action and lead to the chief phenomena of day and night and the succession of the seasons.

Relatively slight tho the perturbations may be, however, they are sufficient to make noteworthy changes in the apparent position of the sun and moon as viewed with modern astronomical instruments; and they can by no means be ignored by the navigator who will determine the position of his ship within safe limits of error. And so it has been the work of the practical astronomers to record thousands on thousands of observations, giving with precise accuracy the location of sun, moon, planets, and various stars at given times; and these observations have furnished the basis for the elaborate calculations of the mathematical astronomers upon which the tables are based that in their final form make up the *Nautical Almanac*, to which we have already more than once referred.

These calculations take into account the precise nature of the perturbing influences that are exerted on the earth and on the moon on any given day, and hence lead to the accurate prediction as to the exact relative positions of these bodies on that day. Stated otherwise, they show the precise position in the heavens which will be held at any given time by the sun for example, or by the important planets, as viewed from the earth. How elaborate these computations are may be inferred from the statement that the late Professor Simon Newcomb used about fifty thousand separate and distinct observations in preparing his tables of the sun. Once calculated, however, these tables of Pro-

fessor Newcomb are so comprehensive as to supply data from which the exact position of the sun can be found for any day between the years 1200 B.C. and 2300 A.D., a stretch of some thirty-five centuries.

Such a statement makes it clear how very crude and vague the deductions must have been from the observations of navigators, however accurately made, prior to the time when such tables as those of the *Nautical Almanac* had been prepared. Fully to appreciate this, it is necessary to understand that the observations supplied in such profusion for the use of the mathematical astronomer are in themselves subject to errors that might seriously vitiate the results of the final computation. They must, therefore, be made with the utmost accuracy, and with instruments specially prepared for the purpose. The chief of these instruments is not the gigantic telescope but the small and relatively simple apparatus known as a transit instrument. This constitutes essentially a small telescope poised on very carefully adjusted trunnions, in such a way that it revolves in a vertical axis, bringing into view any celestial body that is exactly on the meridian, and bodies in this position only. To make observation of the transit—that is to say the passage across the meridian line—of any given body more accurate, the transit instrument has stretched vertically across the center of its field of vision a spider-web, or a series of parallel spider-webs; in order, in the latter case, that the mean time of several observations may be taken.

So exceedingly difficult is it to manufacture

and mount an instrument of requisite nicety of adjustment, that the effort has almost baffled the ingenuity of the mechanic. Sir George Airy, in making a transit instrument for use at the Royal Observatory at Greenwich, required the trunnions on which it was to be mounted to be ground truly cylindrical in form within a variation of one thirty-two-thousandth of an inch as determined by a delicate spirit level. Even when all but absolute precision has been obtained, however, it is quite impossible to maintain it, as the slightest variation of temperature—due perhaps to the application of the hand to one of the pillars on which the trunnions rest—may disturb the precise direction of the spider-webs and so militate against absolute accuracy of observation. The instrument must, therefore, be constantly tested and its exact range of errors noted and allowed for.

To devote so much labor to details, merely in the effort to determine the precise moment at which a star or planet crosses the meridian, would seem to be an absurd magnification of trifles. But when we reflect that the prime object of such observations is to supply practical data which will be of service in enabling navigators on all the seas of the globe to bring their ships safely to port, the matter takes on quite another aspect. We have here, obviously, another and a very striking illustration of the close relationship that obtains between the work of the theoretical devotee of science and that of the practical man of affairs.

SOUNDINGS AND CHARTS

Tho the navigator, thanks to his compass, sextant, and *Nautical Almanac*, may determine with a high degree of precision his exact location, yet even the best observations do not enable him to approach a coast without safeguarding his ship by the use of another piece of mechanism calculated to test the depth of the waters in which he finds himself at any given moment. In its most primitive form—in which form, by the bye, it is still almost universally employed—this apparatus is called the lead,—so called with much propriety because it consists essentially of a lump of lead or other heavy weight attached to a small rope. Knots in the rope enable the sailor who manipulates the lead to note at a glance the depth to which it sinks. Most ocean travelers have seen a sailor heaving the lead repeatedly at the side of the ship and noting the depth of the water, particularly as the ship approaches the Long Island shore.

While this simple form of lead suffices for ordinary purposes, when the chief information sought is as to whether the water is deeper than the draft of the ship, it is at best only a rough and ready means of testing the depth in relatively shallow waters. For deeper waters and to test with greater accuracy the depths of uncharted regions and in particular to determine the character of the sea bottom at any given place, more elaborate apparatuses are employed. One of the most useful of these is the invention of the late Lord Kelvin. In this the lead is re-

placed by a cannon-ball perforated and containing a cylinder which is detached when the weight reaches the bottom and is drawn to the surface filled with sand or mud, the cannon-ball remaining at the bottom. In another form of patent lead, a float becomes detached so soon as the weight strikes the bottom and comes at once to the surface, thus recording the fact that the bottom has been reached,—a fact not always easy to appreciate by the mere feel of the line when the water is fairly deep.

It is obvious that however well informed the navigator may be as to his precise latitude and longitude, he can feel no safety unless he is equally well informed as to the depth of the water, the proximity of land, the presence or absence of shallows in the region, and the like. He must, therefore, as a matter of course, be provided with maps and charts on which these things are recorded. From the days when navigation first became a science, unceasing efforts have been made to provide such maps and charts for every known portion of the globe. Geographical surveys, with the aid of the method of triangulation, have been made along all coasts, and elaborate series of soundings taken for a long distance from the coast line, and there are now few regions into which a ship ordinarily sails, or is likely to be carried by accident, for which elaborate charts, both of coast lines and of soundings, have not been provided. The experienced navigator is able to direct his ship with safety along coasts that he visits for the first time, or to enter any important harbor on the globe without requiring the services of a

local pilot,—albeit the desire to take no undue risk makes it usual to accept such services.

Time was, however, when maps and charts were not to be had, and when in consequence the navigator who started on his voyages of exploration was undertaking a feat never free from hazard. Until the time of Mercator there was not even uniformity of method among map-makers in the charting of regions that had been explored. The thing seems simple enough now, thanks to the maps with which every one has been familiar since childhood. But it required no small exercise of ingenuity to devise a reasonably satisfactory method of representing on a flat surface regions that in reality are distributed over the surface of a globe. The method devised by Mercator, and which, as every one knows, is now universally adopted, consists in drawing the meridian as parallel lines, giving therefore a most distorted presentation of the globe, in which the distance between the meridians at the poles—where in reality there is no distance at all—is precisely as great as at the equator. To make amends for this distortion, the parallels of latitude are not drawn equidistant, as in reality they practically are on the globe, but are spaced farther and farther apart, as we advance from the equator toward either pole. The net result is that an island in the arctic region would be represented on the map several times as large as an island actually the same size but located near the equator. Doubtless most of us habitually conceive Alaska and Greenland to be vastly more extensive regions than they really are, because of our familiarity

with maps showing this so-called "Mercator's projection."

Of course, maps are also made that hold to the true proportions, representing the lines of latitude as equidistant and the meridians of longitude as lines converging to a point at the poles. But while such a map as this has certain advantages—giving, for example, a correct notion of the relative sizes of polar and other land masses—it is otherwise confusing, inasmuch as places that really lie directly in the north and south line can not be so represented except just at the middle of the map, and it is very difficult for the ordinary user of the map to gain a clear notion as to the actual points of the compass. A satisfactory compromise may be effected, however, by using Mercator's projection for maps showing wide areas, while the other method is employed for local maps.

THE LURE OF THE UNKNOWN

While the average man, even with well developed traveling instincts, would perhaps prefer always to feel that he is sailing in well-charted waters and along carefully surveyed coasts, there have been in every generation men who delighted in taking risks, and for whom half the charm of a voyage must always lie in its dangers. Such men have been the pioneers in exploring the new regions of the globe. That there was no dearth of such restless spirits in classical times and even in the Dark Ages, records that have come down to us sufficiently attest. For the most part, however, their names have not

been preserved to us. But since the ushering in of the period which we to-day think of as the beginning of modern times, records have been kept of all-important voyages of discovery, and at least the main outlines of the story of the conquest of the zones are familiar to every one.

Some of the earliest explorers, most notable among whom was the Italian Marco Polo, traveled eastward from the Mediterranean and hence journeyed largely by land. But soon afterward, thanks to the introduction of the compass,—which instrument Marco Polo has sometimes been mistakenly accredited with bringing from the East,—the adventurers began to cast longing eyes out toward the western horizons. Among the first conspicuous and inspiriting results were the discoveries of the groups of islands known as the Cape Verdes and the Azores. The Canary Islands were visited by Spaniards even earlier, and became the subject of controversy with the other chief maritime nation of the period, the Portuguese.

When the controversy was adjusted the Spaniards were left in possession of the Canaries, but the Portuguese were given by treaty the exclusive right to explore the coast of Africa. Following up sundry tentative efforts, the daring Portuguese navigator, Bartholomeo Dias, in the year 1487, passed to the southernmost extremity of Africa, which he christened the Cape of Good Hope. At last, then, it had been shown that Africa did not offer an interminable barrier to the passage to the fabled land of treasures in the East. Before any one had ventured to follow

out the clues which the discovery of the Cape had presented, however, Columbus had seemingly solved the problem in another way by sailing out boldly into the West and supposedly coming to the East Indies in 1492.

The western route was barred to the Portuguese, but the eastern one remained open to them, and before the close of the century Vasco da Gama had set out on the voyage that ultimately led him to India by way of the Cape (1497-1500 A.D.). Twenty years later another Portuguese navigator, Magellan by name, started on what must ever remain the most memorable of voyages, save only that of Columbus. Magellan rounded the southern point of South America and in 1521 reached the Philippines, where he died. His companions continued the voyage and accomplished ultimately the circumnavigation of the globe; and in so doing afforded the first unequivocal practical demonstration, of a character calculated to appeal to the generality of uncultured men of the time, that the world is actually round.

Two routes from Europe to the Indies had thus been established, but both of them were open to the objection that they necessitated long detours to the South. To the geographers of the time it seemed more than probable that a shorter route could be established by sailing northward and coasting along the shores either of Europe to the East or—what seemed more probable—of America to the West. Toward the close of the sixteenth century the ships of the Dutch navigators had penetrated to Nova Zembla, and a few years later Henry Hudson visited Spitzbergen,

thus inaugurating the long series of arctic expeditions. Then Hudson, still sailing under the Dutch flag, made heroic efforts to find the fabled northwest passage, only to meet his doom in the region of the Bay that has since borne his name.

THE QUEST OF THE POLES

This was in the year 1610. For long generations thereafter successors of Hudson were to keep up the futile quest; and when finally it had been clearly established that no northwest passage to the Pacific could be made available, owing to the climate, the zest for arctic exploration did not abate, but its goal was changed from the hypothetical northwest passage to the geographical pole.

Henry Hudson had in his day established a farthest North record of about the eighty-second parallel of latitude—leaving only about five hundred miles to be traversed. But three centuries were required in which to compass this relatively small gap. Expedition after expedition penetrated as far as human endurance under given conditions could carry it. Some of the explorers returned with vivid tales of the rigors of the arctic climate; others fell victims to conditions that they could not overcome. But the seventeenth, eighteenth, and nineteenth centuries passed and left the "Boreal Center" undiscovered.

Toward the close of the nineteenth century the efforts of explorers seemed to be redoubled and one famous expedition after another established new records of "farthest North." The names

of Nansen, the Duke of the Abruzzi, and Peary, became familiar to a generation whose imagination seemed curiously in sympathy with that lure of the North which determined the life activities of so many would-be discoverers. So when in the early Autumn of 1909 it was suddenly announced that two explorers in succession had at last, in the picturesque phrasing of one of them, "penetrated the Boreal Center and plucked the polar prize," the popular mind was stirred as it has seldom been by any other event not having either a directly personal or an international political significance.

The two men whose claims to have discovered the pole were thus announced in such spectacular fashion were Dr. Frederick A. Cook, of Brooklyn, and Lieutenant Commander Robert E. Peary, of the United States Navy. Dr. Cook claimed to have reached the pole, accompanied only by two Eskimo companions, on the twenty-first day of April, 1908. Commander Peary reported that he had reached the pole, accompanied by Mr. Matthew H. Henson and four Eskimos, on the seventh day of April, 1909.

The controversy that ensued regarding the authenticity of these alleged discoveries is not likely to be forgotten by any reader of our generation. Its merits and demerits have no particular concern for the purely scientific inquirer. At best, as Professor Pickering, of Harvard, is reported to have said, "the quest of the pole is a good sporting event," rather than an enterprise of great scientific significance. It suffices for our present purpose, therefore, to know that Dr. Cook's records, as adjudged by the tribunal of the

University of Copenhagen, to which they were sent, were pronounced inadequate to demonstrate the validity of his claim; whereas Peary and Henson were adjudged by the American Geographical Society, after inspection of the records, to have accomplished what was claimed for them. What has greater interest from the present standpoint is the question, which the controversy brought actively to the minds of the unscientific public, as to how tests are made which determine, in the mind of the explorer himself, the fact of his arrival at the pole.

The question has, indeed, been largely answered in the earlier pages of this chapter, in our discussion of the sextant and the *Nautical Almanac;* for these constitute the essential equipment of the arctic explorer no less than of the navigators of the seas of more accessible latitudes. There is one important matter of detail, however, that remains to be noted. This relates to the manner of using the sextant. On the ocean, as we have seen, the navigator levels the instrument at the visible horizon; but it is obvious that on land or on the irregular ice-fields of the arctic seas no visible horizon can be depended upon as a basis for measuring the altitude of sun or stars. So an artificial horizon must be supplied.

The problem is solved by the use of a reflecting surface, which may consist of an ordinary mirror or a dish of mercury. The glass reflector must be adjusted in the horizontal plane with the aid of spirit levels; mercury on the other hand, being liquid, presents a horizontal surface under the action of gravitation. Unfortunately mercury freezes at about 39 degrees below zero; it is there-

fore often necessary for the arctic explorer to melt it with a spirit lamp before he can make use of it. These, however, are details aside from which the principles of use of glass and mercury horizon are identical. The method consists simply in viewing the reflected image of the celestial body—which in practise in the arctic regions is usually the sun—and so adjusting the sextant that the direct image coincides with the reflected one. The angle thus measured will represent twice the angular elevation of the body in question above the horizon,—this being, as we have seen, the information which the user of the sextant desires.

Of course the explorer makes his "dash for the pole" in a season when the sun is perpetually above the horizon. As he approaches the pole the course of the sun becomes apparently more and more nearly circular, departing less and less from the same altitude. Hence it becomes increasingly difficult to determine by observation the exact time when the sun is at its highest point. But it becomes less and less important to do so as the actual proximity of the pole is approached; and as viewed from the pole itself the sun, circling a practically uniform course, varies its height in the course of twenty-four hours only by the trifling amount which represents its climb toward the summer solstice. Such being the case, an altitude observation of the sun may be made by an observer at the pole at any hour of the day with equal facility, and it is only necessary for him to know from his chronometer the day of the month in order that he may determine from the *Nautical Almanac* whether the ob-

servation really places him at ninety degrees of latitude. Nor indeed is it necessary that he should know the exact day provided he can make a series of observations at intervals of an hour or two. For if these successive observations reveal the sun at the same altitude, it requires no *Almanac* and absolutely no calculation of any kind to tell him that his location is that of the pole.

The observation might indeed be made with a fair degree of accuracy without the use of the sextant or of any astronomical equivalent more elaborate than, let us say, an ordinary lead pencil. It would only be necessary to push the point of the pencil into a level surface of ice or snow and leave it standing there in a vertical position. If, then, the shadow cast by the pencil were noted from time to time, it would be observed that its length is always the same; that, in other words, the end of the shadow as it moves slowly about with the sun describes a circle in the course of twenty-four hours. If the atmospheric conditions had remained uniform, so that there was no variation in the amount of refraction to which the sun's rays were subjected, the circle thus described would be almost perfect, and would in itself afford an indication that would appeal to the least scientific of observers. It should be observed, however, that the circle would not be quite perfect unless the observation was made on the day of the solstice; since at all other times the sun is either rising or falling.

But while rough approximations might thus readily be made, the attainment of absolute accuracy of observation would be quite another

matter. The low elevation of the sun and the extreme cold would make accurate instrumental observations difficult; and it is conceivable that the explorer who had the misfortune to encounter cloudy weather, and who therefore gained only a brief view of the sun, might be left in doubt as to whether he had really reached the goal of his ambition. Fortunately, however, the explorers who thus far claim to have reached the poles record uninterruptedly fair weather, enabling observations to be taken hour after hour. Under these circumstances, there could be no possibility of mistake as to the general location, altho perhaps no observation, under the existing conditions, could make sure of locating the precise position of the pole within a few miles.

A curious anomaly incident to the unique geographical location of the North Pole is that to the observer stationed there all directions are directly south. Yet of course all directions are not one, and the query may arise as to how an explorer who has reached the pole may know in what direction to start on his return voyage. The answer is supplied by the compass, which—perforce pointing straight south—indicates the position of the magnetic pole and so makes clear in which direction lies the coast of Labrador. Moreover, if the explorer is provided with reliable chronometers, which of course record the time at a given meridian—say that of Greenwich—these will enable him to determine by the simplest calculation what particular region lies directly beneath the sun at any given time. If, for example, his chronometer shows five o'clock Greenwich time, he knows that the sun's position, as observed at

the moment, marks the meridian five hours (*i.e.*, 75° of longitude) west of Greenwich.

What has been said of observations made at the North Pole applies also (with obvious reversal) to observations made at the opposite axis of the earth. In everything else save in the matter of low temperature, however, conditions at these two extremes are utterly different. Sir Ernest Shackleton, approaching within one hundred and eleven miles of the South Pole in 1809, concluded that the high Antarctic Continent over which he had traveled must extend beyond his forbidden goal: that the South Pole was located on frozen land, not on a frozen ocean.

On December 14, 1911, Captain Roald Amundsen, of Norway, with four countrymen as companions, completed the task so nearly accomplished by Shackleton, by actually attaining the South Pole. He found this on a high plateau, some ten thousand feet above sea level, only to be reached after crossing mountain ranges, some of whose peaks are fifteen thousand feet high. So that, altho his journey was made on land instead of shifting ice, his task was quite as arduous as that of Peary and his companions. His own account of the crowning incident is dramatic in its simplicity.

"We had got our silk flag ready in the morning," he says. "We gathered round it now, each man taking hold, and together we planted it here —at the same time naming the plateau, on which the pole is situated, 'King Haakon the Seventh's Wilds.' We had reached the pole with three sledges and seventeen dogs"—five sturdy Vikings annexing a Continent.

II

THE HIGHWAY OF THE WATERS

The story of the development of the steamboat begins with the futile efforts of several more or less visionary enthusiasts who were contemporaries of James Watt, and who thought they saw great possibilities in the steam-engine as a motive power to take the place of oars and sails for the propulsion of ships.

Among the first of these was an American named John Fitch. Judged by the practical results of his efforts, he was not a highly successful inventor; as a prophet, however, and as an experimenter whose efforts fell just short of attainment, he deserves a conspicuous place in the history of an epoch-making discovery. Yet his prophecy was based on his failures. From 1780, for twenty years he strove to perfect a steamboat. His efforts did not carry him far beyond the experimental stage. But his courage and enthusiasm never waned. "Whether I bring the steamboat to perfection or not," he declared, "it will some time in the future be the mode of crossing the Atlantic for packets and armed vessels."

At that very time Benjamin Franklin said this would never be. But twenty years later Fulton's *Clermont* paddled up the Hudson River from New York to Albany and opened the era that saw Fitch's prophecy fulfilled. This was in 1807—

a year that must stand as the most momentous in maritime history. In that year the little *Clermont* steamed slowly from New York to Albany, a distance of one hundred and fifty miles, in thirty-two hours, unaided by sails or oars, and propelled entirely by steam-power. A sailboat could cover the distance in the same number of hours; a modern torpedo-boat in one sixth the time. Yet no performance of any boat, before or since, had such far-reaching effects upon the progress of the world.

When Fulton turned his attention from his favorite theme—the invention of a submarine boat—and took up the question of perfecting a boat propelled by steam, he did not find himself the first or the only inventor in the field. For a hundred years, in round numbers, men had been wrestling with the question of applying steam pressure to boat propulsion. All manner of more or less ingenious devices had been conceived, most of them having a germ of success in the principles involved, but all of them being failures in actual practise.

Among the most promising of these first steamboats were those in which the propeller, or the paddle-wheel, was tried; but neither of these methods was looked upon favorably at first. Less promising was one in which the motive power was a jet of water pumped through a submerged tube —a principle that still periodically fascinates certain modern inventors.

But the boats that seemed to have come nearer attaining practical success for the moment were those in which several sets of oars worked by steam were placed vertically on each side of the

hull, the machinery so arranged that the oars were dipt into the water and drawn sternward by one motion of the machinery, raised and carried toward the bow by the opposite motion. In some of these boats it was planned to have four sets of oars, two sets on each side, which were to work alternately, so that while one set was traveling forward through the air, its mate would be paddling through the water, thus insuring a continuous forward impulse. But the machinery for these boats proved to be too cumbersome and complicated for practical results, and this idea was finally abandoned. The jet of water did not prove any more successful, and but two other methods were available—the propeller and the paddle-wheel.

Both of these methods of utilizing the power of moving water had been familiar in the form of the Archimedian screw and the commonplace overshot or undershot mill-wheel. In these examples, of course, the force of the water was used to move machinery, reversing the action of the paddle-wheel of the boat. And yet the principles were identical. Obviously if the conditions were reversed, and the undershot mill-wheel, for example, forced against the water with corresponding power, the propulsive effect might be great enough—since action and reaction are equal—to move a boat of considerable size. But curiously enough, at the time when Fulton began his experiments there was a wave of general belief that when this principle was applied to boats it would fail. The reason for this lay in the fact that several such boats had been built from time to time, and all had failed. The

fault, of course, lay in some other place than in their paddle-wheels; but for the time being the wheel, and not the machinery, was shouldered with the blame.

Just a hundred years before Fulton finally produced his practical paddle-wheel steamboat, a prototype was built by the Spaniard, Blasco de Gary. In 1707, this inventor constructed a model paddle-wheel steamboat, and tried it upon the river Fulda. But this model boat failed to work, and the experiment was soon forgotten.

Twenty-five years later Jonathan Hulls, of England, patented a marine engine which he proposed to use in a boat which was to be propelled by a stern wheel. His idea was to use his boats as tug- or tow-boats, and to equip the larger vessels themselves with steam. But his engines were defective and his boats did not achieve commercial success.

During the time of the American Revolution, a French inventor, the Marquis de Jouffroy, made several interesting experiments with steam-propelled boats, using the principle of the paddle which was dipt and raised alternately as referred to a few pages back. His boats made several public trials, one of them ascending the Seine against the current; but nevertheless, the French government refused to grant the inventor a patent. Presumably, therefore, the boat was not considered a practical success in official circles; and this view is tacitly conceded by the fact that no more boats of its type were constructed. Had they been really practical steamboats it is a fair presumption that others would have been constructed and put into operation, regardless of

patents. Nevertheless, in France to-day, the Marquis de Jouffroy is often referred to as the father of steam navigation.

The idea of propelling a boat by means of a jet of water pumped out at the stern by steam pumps was given a practical test in 1784, by James Rumsey. His boat made a trial trip on the Potomac River in September of that year, General Washington and other army officers being present on this occasion. The boat was able to make fairly good progress through the water, and seemed so promising that a company was formed by capitalists known as the Rumsey Society, for promoting the idea and building more boats. Rumsey was sent to England where he undertook the construction of another boat, meanwhile taking out patents in Great Britain, France and Holland. Before his boat was completed, however, he died suddenly, and the Rumsey Society passed out of existence shortly afterwards.

An even closer approach to practical success was made in Scotland by James Symington, who, in 1788, in association with two other Scotchmen, Miller and Taylor, constructed a boat consisting of two hulls, with a paddle-wheel between them worked by a steam-engine. This boat worked so well that in 1801 Lord Dundas engaged Symington to build a smaller boat to be used for towing on the Caledonian Canal. This boat, called the *Charlotte Dundas,* completed in 1802, is said to have been capable of towing a vessel of one hundred and forty tons "nearly four miles an hour." But in doing this the resulting "wash" so threatened the banks of the

canal that the vessel was laid up and finally rotted and fell to pieces.

By many impartial judges this boat is considered the first practical steamboat. Its failure to establish its claim seems to have been due to the force of circumstances rather than to any inherent defects. Symington was too poor to pursue his work independently, and was deterred by the attitude of James Watt, who "predicted the failure of his engine, and threatened him with legal penalties if it succeeded." And when at last he received an order for eight smaller vessels from the Duke of Bridgewater, his patron died before the details of the agreement had been completed. So that while he failed in accomplishing what was done by Fulton a few years later, it is certain that, as Woodcraft says, "He combined for the first time those improvements which constitute the present sysem of steam navigation."

Some of Symington's engines have been preserved and one of them is now in the Patent Office Museum in London. Since the beginning of practical steam navigation this engine has been tested several times, the result showing that Woodcraft's estimate is not overdrawn.

While Symington was thus perfecting a paddle-boat, an American, Col. John Stevens, of Hoboken, New Jersey, was on the verge of accomplishing the same end with a screw-propeller boat —a form of steamship that did not come into use until some forty years later.

Stevens also invented what he called a "rotary engine" which was really an engine constructed on the same principle as the modern turbine engine. It was a small affair which he placed in a

skiff, and used for turning the screw-propeller of a boat which was able to travel at a rate of three or four miles an hour on the North River, during the fall of 1802. But Stevens found so much difficulty in packing the blades of this engine without causing too much friction that he finally abandoned it for the more common type of reciprocating engine. But if this little steamboat had its defects, it nevertheless contained the germs of two great features of steam navigation—the screw propeller and the turbine engine, the advantage of the first of which was not recognized for nearly half a century, and the other not until almost a full century later.

In 1804 Stevens produced another propeller steamboat, this one using the ordinary type of reciprocating engine, and being notable for having twin screws of a pattern practically identical with the screws now in use. This boat was able to steam at a rate of four miles an hour on many occasions, and at times almost double this rate, according to some observers. The engines of this boat are still in existence, and on several occasions since 1804 have been placed in hulls corresponding as nearly as possible to the original, and have demonstrated that they could force the boat through the water at six or eight miles an hour. These engines in a modern hull were exhibited at the Columbian Exposition at Chicago, in 1893. They supply irrefutable evidence that the practical steamboat had been invented at least three years before Fulton's historic voyage in 1807. Yet no one questions that it was Fulton's, not Stevens's, invention that inaugurated steam navigation.

Just why this was so is a little difficult to comprehend at this time, unless it was that Stevens's boat was such a small affair that it did not attract the attention it deserved, as did Fulton's larger boat. And yet we should not be guided too much by retrospective judgment. The significant fact remains that Stevens himself did not have entire confidence in his boat, or in the principle of his screw propeller, as is shown by the fact that three years later, while Fulton was building the *Clermont*, Stevens was also constructing a steamboat, not along the lines of his previous inventions but as a paddle-wheel boat. This leaves little room for doubt that Stevens had not full confidence in the propeller; and when an inventor himself mistrusts his own device, there is little likelihood that any one else will supply the necessary confidence. This may account for the fact that Stevens found difficulty in securing financial backing for his enterprise; and when such backing was found it was for the construction of the paddle-wheel boat, which was finished a few months after Fulton's boat had solved the problem of steam navigation.

FULTON AND THE CLERMONT

As we shall see in another place, Fulton was no novice in the construction of peculiar boats at this time. He had built experimental boats both at home and abroad, was familiar with the principle of the screw and the paddle-wheel, and had come to have absolute confidence in the possibility of propelling boats of a good rate of speed by the use of steam. When he began his now

famous *Clermont*, in the spring of 1807, it was not as an experimental skiff, but as a boat of one hundred and fifty tons burden—half again the size of the boats in which Columbus had discovered America—to be placed in commission between Albany and New York City. By August, this boat was completed, and the engines in place, and, under her own steam, the new boat was moved from the Jersey shipyard where she was constructed, and tied up at a New York dock. On August 7th, she started on her maiden trip up the Hudson. To the astonishment of practically every one of the persons in the great throng that had gathered along the shores, she left her dock in due course, and with wind and tide against her, steamed up the river at the rate of about five miles an hour. At this speed she covered the entire distance between New York and Albany, settling forever the question of the practicability of steam navigation.

The impression this fire-belching monster made upon the sleepy inhabitants as it passed along the river can be readily imagined. An eye-witness account of this first passage of the *Clermont* has been given by an inhabitant at the half-way point near Poughkeepsie.

"It was the early autumn in 1807," he wrote, "that a knot of villagers was gathered on the high bluff just opposite Poughkeepsie, on the west bank of the Hudson, attracted by the appearance of a strange, dark-looking craft which was slowly making its way up the river. Some imagined it to be a sea-monster, while others did not hesitate to express their belief that it was a sign of the approaching Judgment. What

seemed strange in the vessel was the substitution of lofty and straight black smoke-pipes, rising from the deck, instead of the gracefully tapered mast that commonly stood on the vessels navigating the stream; and, in place of spars and rigging, the curious play of the working-beam and pistons, and the slow turning and splashing of the huge, naked paddle-wheels, met the astonished gaze. The dense clouds of smoke as they rose wave upon wave added still more to the wonderment of the rustics.

"This strange looking craft was the *Clermont*, on her trial trip to Albany. On her return-trip the curiosity she excited was scarcely less intense—the whole country talked of nothing but the sea-monster, belching fire and smoke. The fishermen became terrified and rowed homewards, and they saw nothing but destruction devastating their fishing-grounds; while the wreaths of black vapor, and rushing noise of the paddle-wheels, foaming with the stirred-up water, produced great excitement among the boatmen."

While acknowledging fully Fulton's right to the claim of being "the father of steam navigation," as he has been called, there is no evidence to show that he introduced any new principle or discovery in his application of steam to the *Clermont*. The boiler, engine, paddle-wheel—every part of the boat had been known for years. Yet this does not detract from the glory of Fulton, who first combined this scattered knowledge in a practical way, and demonstrated its practicality beyond question.

SEA-GOING STEAMSHIPS

The first war steamer and ocean steamer ever attempted was built by Fulton, in 1813. It was called the *Demolgos*, and was not a practical success, and made no attempts to take protracted ocean voyages. The first steamship to cross was the *Savannah* in 1819. She made the voyage from Savannah to Liverpool in twenty-five days, using her paddle-wheels part of the time, but at other times depending entirely upon her sails. She was a boat of three hundred and fifty tons, and her paddle-wheels were arranged so that they could be hauled in upon the deck and stowed away in bad weather.

Following the *Savannah* several similar combination sailing and steam-propelled boats were constructed, the navigators coming to have more and more faith in the possibilities of steam, so that less sail was carried. These vessels continued to reduce the time of the passage between Europe and America, until the voyage had been made in about seventeen days. Then, in 1838, two vessels, the *Sirius* and the *Great Western*, for the first time using steam alone as motive power, made record voyages, the *Great Western* crossing in twelve days, seven and a half hours. This was considered remarkable time—an average speed of over two hundred miles a day. Something like four hundred and fifty tons of coal were consumed on the voyage, which imprest many as a great extravagance of fuel. Some of the ocean liners at present consume more than twice this amount in a single day.

On July 4, 1840, the *Britannia*, the first steamer

of the Cunard Line, started on its maiden voyage from Liverpool to Boston. The voyage was made in fourteen days, among the passengers being Samuel Cunard, a Quaker of Halifax, who was the founder of the enterprise. The population of Boston went mad on the arrival of this boat; streets and buildings were decorated, and the day was given over to the regular holiday amusements. Cunard received upward of eighteen hundred invitations to dinner that evening.

The year 1840, then, may be considered as one of the vital years in the progress of steam navigation. Since that time no year has passed without seeing some important addition and improvement made in the conquest of the ocean, either in size, shape, or speed of the "greyhounds."

SHIPS BUILT OF IRON AND STEEL

Even before the introduction of steam as a motive power for boats shipbuilders had been casting about for some satisfactory substitute for wood in the construction of vessels. One reason for this was that suitable wood was becoming scarce and very expensive. But also there was a limit to the size that a wooden vessel might be built with safety. A wooden boat more than three hundred feet long cannot be constructed without having dangerous structural weakness.

Naturally the idea that the only suitable material for boat-building was something lighter than water,—something that would float—which had been handed down traditionally for thousands of years, could not be overcome in a moment. *And surely* such a heavy substance as iron would

not be likely to suggest itself to the average shipbuilder. But at the beginning of the nineteenth century rapid strides were being made in theoretical, as well as applied science, and the idea of using metal in place of wood for shipbuilding began to take practical form.

Richard Trevithick, whose remarkable experiments in locomotive building have been noted in another chapter, had planned an iron ship as early as 1809. He did not actually construct a vessel, but he made detailed plans of one—not merely a boat with an iron hull, but with decks, beams, masts, yards, and spars made of the same material. It was nearly ten years after Trevithick drew his plans, however, before the first iron ship was constructed. Then Thomas Wilson, of Glasgow, built a vessel on practically the same lines suggested by Trevithick.

This vessel, finished in 1818, and called the *Vulcan*, was the pioneer of all iron boats. For at least sixty years it remained in active service. Indeed, for aught that is known to the contrary, this first iron boat may be still in use in some capacity.

One of the most surprizing and interesting things to shipbuilders about the *Vulcan*, and the boats that were constructed after her, was the fact that they were actually lighter in proportion to their carrying capacity than ships of corresponding size built of wood. In wooden cargo ships the weight of the hull and fittings varies from 35 to 45 per cent. of the total displacement, while iron vessels vary from 25 to 30 per cent. This was a vital point in favor of the iron vessel, and one that appealed directly to practical build-

ers. But the public at large looked askance at the new vessels. To "sink like a stone" was proverbial; and every one knows that iron sinks quite as readily as stone.

But very soon a convincing demonstration of the strength of iron vessels brought them into favor. A great storm, sweeping along the coast of Great Britain in 1835, drove many vessels on shore, among them an iron steamboat just making her maiden voyage. The wooden vessels without exception were wrecked, most of them destroyed, but the iron vessel, altho subjected to the same conditions, escaped without injury, thanks to the material and the new method of her construction.

From that time the position of the iron steamship was assured. And whereas sea voyagers had formerly looked askance at iron passenger boats they now began to distrust those built of wood. By the middle of the century, iron shipbuilding was at its height, and in the decade immediately following, the *Great Eastern* was finished—possibly the largest and most remarkable structure ever built of iron, on land or sea. She was 692 feet in length. In recent years larger ships have been constructed, but these ships are made of steel.

The *Great Eastern* marked an epoch in shipbuilding. In size she was a generation ahead of her time, but the innovations in the method of her construction gave the cue to modern revolutionary shipbuilding methods.

Mr. Scott Russell and Mr. Brunel were, between them, entitled to the credit of the design, *which, on* account of the exceptional size of the

ship, presented special difficulties, and involved a total departure from ordinary practise.

Mr. Scott Russell had systematically, in his own previous practise, constructed iron ships with cellular bottoms, but the cells had only five sides, the uppermost side on the inside being uncovered. Over a large portion, however, of the bottom of the *Great Eastern* the cells were completed by the addition of an inner bottom, which added greatly both to the strength and to the safety of the ship. It was also Mr. Brunel's idea that the great ship should be propelled by both paddles and screw. Mr. Scott Russell was responsible for the lines and dimensions, and also for the longitudinal system of framing, with its numerous complete and partial transverse and longitudinal bulkheads.

The great value of the system adopted in her construction was proved by an accident which occurred during one of her transatlantic voyages. She ran against a pointed rock, but the voyage was continued without hindrance. It was afterwards found that holes of the combined length of over 100 feet had been torn in her outer bottom; but, thanks to the inner water-tight skin, no water was admitted. It is the opinion of some marine experts that the *Great Eastern* would similarly have weathered the blow from an iceberg that sent the superb *Titanic* to the bottom, with sixteen hundred souls, on that fateful 14th of April, 1912. But this, of course, is only conjectural.

Between the years 1860 and 1870 great improvements were made in marine engines, and screw-steamers very generally replaced side-wheel

boats for ocean traffic. The improvements in the engines consisted largely in the use of higher pressures, surface condensation, and compounding of the cylinders, which resulted in a saving of about half the amount of fuel over engines of the older type. As a result steamers were able to compete successfully with the sailing ships, even as freighters for long voyages, such as those between Europe and Australia.

During the reactive period in France immediately following the Franco-Prussian war, when there was great activity in shipbuilding, the use of mild steel plates in place of wrought iron was tried. The superiority of this material over iron was quickly demonstrated, and as the cost of steel was constantly lessening, thanks to the newly discovered methods of production, steel practically replaced iron in ship construction after this time.

It was during this same period that a new type of passenger steamer was produced—the "ocean greyhound." The first of these was the *Oceanic* built by the White Star Company in 1871. This ship was remarkable in many ways. Her length, four hundred and twenty feet, was more than ten times her beam; iron railings were substituted for bulwarks; and the passenger quarters were shifted from the position near the stern to the middle of the vessel. All these changes proved to be distinct improvements, and the *Oceanic* became at once the most popular, as well as the fastest ocean liner.

Like all the other boats of the seventies and early eighties, the *Oceanic* was a single-screw vessel. The advantage of double propellers in

case of accident had long been recognized, but hitherto twin-screws had not proved as efficient as a single screw in developing speed. But in 1888 the *City of Paris* (now the *Philadelphia*) a twin-screw boat, began making new speed records, and the following year her sister ship, the *New York*, and the new *Majestic* and *Teutonic*, entering into the ocean-record contests, cut the time of the passage between Europe and America to less than six days.

The advantages of the double-screw over the single are so many and so manifest as to leave no question as to their superiority. The disabling of the shaft or screw of the single-screw steamer or the derangement of her rudder renders the vessel helpless. Not so the twin-screw ship; for on such ships the screws can be used for steering as well as propelling. And it has happened many times that twin-screw ships have crossed the ocean with the steering gear disabled, or with one screw entirely out of commission.

THE TRIUMPH OF THE TURBINE

In recent years the greatest revolutionary step in steamship construction has been the invention and development of the turbine engine, the mechanism of which has been described elsewhere. Since the day of the little *Turbinia*, whose speed astonished the nautical world, the limit for size and speed of ships has again been materially advanced, and no thinking person will venture to predict restricting limits without a modifying question mark.

At the beginning of the twentieth century a

keen rivalry had developed between England and the Continent for supremacy in transatlantic traffic, America having dropt out of the race. The Germans in particular had produced fast boats, such as the *Deutschland* and *Kaiser Wilhelm II,* which for several years held the ocean record for speed. But meanwhile the turbine engine was being perfected in England, the land of its invention, and presently turbine "greyhounds" began crossing the ocean and menacing the records held by the boats equipped with the older type of engine.

The reciprocating marine engine, however, had been steadily improved, until it was a marvel in efficiency. Quadruple expansion engines, driving twin-screws of a size and shape known to develop the greatest efficiency, for several years offered invincible competition to the new type of engine. There were new conditions to be met, new difficulties to be overcome.

A decisive test of the merits of the turbine engine was given in 1905, when the Cunard Company built two vessels, the *Caronia* and *Carmania,* of exactly the same size and shape, the *Caronia* having the highest type of quadruple expansion reciprocating engines, while the *Carmania* was equipped with turbine engines. Here was a fair test of efficiency between the two types. And the turbine boat proved herself the better of the two by developing more than a knot greater speed per hour.

Still the *Carmania* offered no serious competition in speed to several of the German flyers. But in 1908 two more turbine ships, the *Lusitania* and *Mauretania,* began making regular trans-

atlantic voyages, and quickly distanced all competitors.

In the matter of speed these sister ships mark an epoch in navigation. Turbine engines take the place of the usual reciprocating type, acting on four propellers for going ahead and two separate propellers for going astern. These engines develop 68,000 horse-power. Stated in this way these figures convey little idea of the power developed. But when we say that it would take a line of horses one hundred and twenty miles long hitched tandem to develop the power generated in the compact space of the *Mauretania's* engine-room, some idea of the power is gained and this power is surpassed by the new German steamer *Imperator,* of the Hamburg-American Line. Comparative safety against sinking from injury to the hull was provided by the introduction of water-tight compartments half a century ago, as we have seen, tho it is unfortunately true that the example set by the designers of the *Great Eastern* has not always been followed faithfully. Since the beginning of the present century two other revolutionary safety devices have been perfected—wireless telegraphy and the submarine signaling apparatus. The wireless apparatus has been described in another chapter, and as it is used almost as much on land as at sea, can not be considered as solely a nautical appliance. But the submarine signaling device, which is dependent upon water for transmission, is essentially a nautical mechanism.

SUBMARINE SIGNALING

It is difficult for the average landsman to appreciate that the one thing most dreaded by mariners is fog. Dark and boisterous nights which frighten the distressed landsman have no terrors for the sailor. Given an open sea-way he knows that he can ride out any gale that blows. It is the foggy night that fills him with apprehension.

In perfectly still weather the sound of the fog-horn carries far enough, and indicates location well enough so that two ships approaching each other, or a ship approaching a bell-buoy, can detect its location and avoid danger. But this is under favorable conditions; and unfortunately such conditions do not always prevail. And if there is a wind stirring or the sea running high atmospheric sounds can not be depended upon. A fog whistle whose sound ought to carry several miles under ordinary conditions may not be heard more than a ship's length away. And scores of accidents, such as collisions between ships, have happened in fogs, when both vessels were sounding their fog whistles at regular intervals.

When wireless telegraphy was perfected sufficiently to be of practical use, great hopes were entertained that this discovery could be used to give warning and prevent accidents to fog-bound vessels. But experience has shown that its usefulness is confined largely to that of calling for help after the accident, rather than in preventing it. Thus in 1908 when the wireless operator on board the steamer *Republic* flashed his message

broadcast telling ships and shore-stations for hundreds of miles around that his vessel had been run down in a fog and was sinking, he could only give the vessels that hurried to the *Republic's* aid an approximate idea of where they could find her. The use of another electric appliance, of even more recent invention than the wireless telegraph, was necessary for locating the exact position of the stricken ship. This was the submarine signaling device, which utilizes water instead of air as a medium for transmitting sound.

Benjamin Franklin pointed out more than a century ago that water carries sound farther and faster than air and carries it with greater constancy. Density, temperature, and motion of the atmosphere act upon aerial sound waves to reflect and refract them in varying degrees; but these waves are not affected when water is the medium through which they are passing. The knowledge of these facts was turned to little practical account until the closing years of the last century when Arthur J. Mundy, of Boston, and a little later Prof. Elisha Gray, of Chicago, began experiments together that resulted finally in a practical submarine signaling apparatus which is now installed as a system on boats and buoys in dangerous places along the coasts, particularly near the great highways of ocean travel.

The principle upon which this system is based is simply that of sound waves transmitted through the water and detected at a distance by a submerged electrical transmitter. The sound transmitted is usually that of a submerged bell. It is possible for a person whose head is submerged to hear the ringing of such a bell distinctly for a

long distance; but of course for practical purposes such submergence is out of the question. The receiving apparatus of the Mundy-Gray signaling device offers a substitute in the form of a submerged "artificial ear"—an electrical transmitter, connected with a telephone receiver.

In the early experiments a small hollow brass ball filled with water and containing a special form of electrical transmitter was lowered over the side of a ship and connected by insulated wires to the receiver of a telephone in the pilot-house. The sound of a submerged bell could be heard in this manner at a distance of ten or twelve miles. The location of the bell could be determined by having two such brass balls, one on each side of the hull of the vessel, but not submerged to a depth below that of the hull, so that the ship itself acts as a screen in obstructing the sound waves coming from the bell. By listening alternately to the sounds of the bell transmitted through these two submerged balls it was found that the ball on the side of the ship toward the bell gave a distinctly louder sound. By turning the ship so that the sounds were of equal intensity the direction of the bell could be determined as either directly ahead or astern; and by using the compass the exact location could be determined.

But such brass-ball transmitters can be used only when the vessel is moving at a rate not exceeding three miles an hour. They are, therefore, of little value for ocean liners whose reduced speed far exceeds this. But the inventors discovered presently that by using the inside of the outer steel skin of the ship's hull below the water-

line as one side of the brass ball the transmitter would work equally well. Indeed with added improvements, this hollow metal device fastened to the inside of the hull on each side, with connecting wires leading to the pilot-house, in its perfected form will pick up the sound of the submerged bell equally well at any speed, regardless of calm or storm.

The chief defect of this arrangement was that the sound of the pulsations of the engines of the ship were also heard and interfered seriously with the detection of the sound of the bell. But presently a receiving device was perfected which ignored all sounds but those of the bell, thus giving the mariner a means of protection against accidents that could be depended upon absolutely at all times regardless of speed or weather conditions.

When this stage of perfection of the signaling device was reached the various governments began installing the instruments on buoys, lighthouse sites, and lightships, using various mechanical devices for ringing the bells, and timing the strokes so that the mariners could tell by the intervals just what bell he was in touch with, as he knows each lighthouse by the intervals between the flashes of its lights. A further development in the signaling device was to equip ships with submerged bells, as well as with the receiving apparatus. In this way two ships could communicate with each other, or with a shore receiving station, by using the Morse telegraph code, just as in the case of telegraphy.

The maximum distance at which such communication may be detected is about fifteen miles,

and the approximate distance the bell can be gaged from the clearness of the sound heard in the telephone receiver. At the distance of a quarter of a mile the sound of the bell is so loud that it is painful to the listener if the receiver is held against the ear, while at ten or twelve miles the sound is scarcely audible.

One of the most dramatic rescues at sea in recent years was that of the passengers and crew of the steamer *Republic,* referred to a few pages back. When her wireless messages of distress were received a score of vessels went groping in the fog to her assistance, while the entire civilized world waited in breathless expectancy. Most of the rescuing vessels, altho constantly in communication with the stricken ship, were unable to locate her. But the successful vessel finally got in touch with the *Republic's* submarine signaling apparatus, and aided by this located the vessel and rescued the crew and passengers.

This is only one instance of the practical application of the submarine signaling apparatus. But its use is not confined to the larger boats. The apparatus can be made so small that even boats the size of a fishing dory may be equipped at least with the sounding device, and thus protected.

On the Newfoundland fishing banks one of the chief causes of loss of life is the running down of the fishing boats in the fog by passing steamers, and also the loss of the dories of the fishermen who are unable to find their way back to their vessels. Many of these fishing vessels now supply each of the attending dories with a submarine bell which weighs about forty pounds and

is run by clockwork. When caught in the fog the fisherman hangs this bell over the side of his dory and thus warns approaching steamers of his position, at the same time affording his own vessel a guide for finding him and picking him up. In this manner the appalling loss of life in the fogs on the fishing banks has been greatly lessened. Thus the submarine signaling device gives aid to the smaller craft as well as the larger vessels.

The size of modern vessels minimizes rolling and pitching. Turbine engines practically eliminate engine vibrations. The danger from fires was practically eliminated by the introduction of iron and steel as building material; the danger of sinking after collisions may be minimized by the division of the ship's hull into longitudinal and transverse water-tight compartments; sensitive instruments as used at present warn the mariner of the presence of icebergs; wireless telegraphy affords a means of calling aid in case of disabled machinery and giving the ship's location in a general way; while the submarine signal makes known the exact location of the stricken vessel in foggy weather. Yet the fate of the *Titanic*, which foundered after a glancing collision with an iceberg on a clear night in a calm sea, gives tragic denial to the claim sometimes put forward that the ocean greyhound is "unsinkable."

MOTOR-DRIVEN SHIPS

Early in September, 1912, a ten-thousand-ton vessel, the *Christian X*, arrived in New York from Hamburg, being the first motor-driven ship to cross the Western Ocean. This voyage was prob-

ably of greater significance than any transatlantic voyage since the first steam-driven vessel crossed the ocean. For it heralded the opening of a new era in maritime affairs.

About the same time a similar ship, the *Selandia,* completed a trip to the Orient from Europe. These vessels are propelled by Diesel engines—gas-engines in which crude oil is converted into power within their cylinders, thus dispensing with cumbersome boilers. This liquid fuel is carried in the ship's double-bottom, thus making available the space occupied by coal-bunkers on steamships. Moreover, the stoking and engine-room force is greatly reduced, while the engine-rooms themselves are cool and clean.

Of equal importance commercially, however, is the fact that these motor-ships consume less weight of fuel mile for mile than the most highly perfected steam-driven vessels. Thus there is not only increased radius of action for the ship, but also increased capacity. And the *Christian X* and *Selandia* are simply forerunners of the fleets of motor-driven war- and passenger-ships now building.

III

SUBMARINE VESSELS

The development of submarine vessels has been one of the slowest in the history of modern inventions. Submarine boats, using submarine torpedoes, were able to destroy ships a hundred years ago; and a little less than half a century ago naval vessels were destroyed in actual warfare by these boats. But curiously enough no vessel has ever been destroyed in actual warfare by a submarine boat since that time. Yet these boats are essentially war-vessels, and, with the exception of boats of the Lake type, of no use whatever for commercial purposes.

Perhaps the explanation for this tardy development lies in the fact that until recent years naval men have not looked with favor upon this style of fighting craft. In Admiral Porter's book, written in 1878, he makes the statement that one of the reasons why they did not show enthusiasm about the submarine made by Robert Fulton early in the nineteenth century was that such boats "menaced the position of the naval men, whose calling would be gone did the little submarine boat supplant the battle-ship." We need not, however, depend upon this statement, made as it was three-quarters of a century after the demonstrations by Fulton, for there are many similar statements made at the time to be had at first hand. Thus Admiral Earl St. Vincent, when opposing the views of William Pitt, who had become

enthusiastic over the possibilities of Fulton's submarines, is on record as having opposed such craft on the ground that by encouraging such development "he was laying the foundation which would do away with the navy." In 1802, M. St. Aubin wrote in this connection, "What will become of the navies, and where will sailors be found to man ships of war, when it is a physical certainty that they may at any time be blown into the air by diving-boats, against which no human foresight can guard them?"

Such opposition has undoubtedly tended to retard the progress of submarine navigation; but be the cause what it may, it has made slow and laborious work of it; and we are only now approaching a solution of the question that seemed almost within grasp a hundred years ago—before the days of steam or electricity.

THE FIRST SUBMARINE

As early as the sixteenth century the possibilities of submarine navigation was the dream of the mariner, and tentative attempts at submarine boats are said to have been made even at an earlier period than this; but the first practical submarine boat capable of navigation entirely submerged for any length of time was made by David Bushnell, of Westbrook (then Saybrook), Maine, U. S. A., in 1775. Details as to the construction of the remarkable craft are recorded in a letter written by the inventor to Thomas Jefferson in 1789, and recorded in the *Transactions of the American Philosophical Society.* In this letter Bushnell says:—

"The external shape of the submarine vessel bore some resemblance to the upper tortoise-shells of equal size, joined together, the place of entrance into the vessel being represented by the opening made by the swell of the shells at the head of the animal. The inside was capable of containing the operator and air sufficient to support him thirty minutes without receiving fresh air. At the bottom, opposite to the entrance, was fixt a quantity of lead for ballast. At one edge, which was directly before the operator, who sat upright, was an oar for rowing forward and backward. At the other edge was a rudder for steering. An aperture at the bottom, with its valves, was designed to admit water for the purpose of descending, and two brass forcing-pumps served to eject the water within when necessary for ascending. At the top there was likewise an oar for ascending or descending, or continuing at any particular depth. A water-gage or barometer determined the depth of descent, a compass directed the course, and a ventilator within supplied the vessel with air when on the surface.

"The vessel was chiefly ballasted with lead fixt to its bottom; when this was not sufficient a quantity was placed within, more or less according to the weight of the operator; its ballast made it so stiff that there was no danger of oversetting. The vessel, with all its appendages and the operator, was of sufficient weight to settle it very low in the water. About two hundred pounds of lead at the bottom for ballast could be let down forty or fifty feet below the vessel; this enabled the operator to rise instantly to the surface of the water in case of accident.

"When the operator would descend, he placed his foot upon the top of a brass valve, depressing it, by which he opened a large aperture in the bottom of the vessel, through which the water entered at his pleasure; when he had admitted a sufficient quantity he descended very gradually; if he admitted too much he ejected as much as was necessary to obtain an equilibrium by the two brass forcing-pumps which were placed at each hand. Whenever the vessel leaked, or he would ascend to the surface, he also made use of these forcing-pumps. When the skilful operator had obtained an equilibrium he would row upward or downward, or continue at any particular depth, with an oar placed near the top of the vessel, formed upon the principle of the screw, the axis of the oar entering the vessel; by turning the oar one way he raised the vessel, by turning it the other he deprest it.

"An oar, formed upon the principle of a screw, was fixt in the fore-part of the vessel; its axis entered the vessel, and being turned one way rowed the vessel forward, but being turned the other way rowed it backward; it was made to be turned by the hand or foot.

"Behind the submarine vessel was a place above the rudder for carrying a large powder magazine. This was made of two pieces of oak timber, large enough when hollowed out to contain one hundred and fifty pounds of powder, with the apparatus used in firing it, and was secured in its place by a screw turned by the operator. A strong piece of rope extended from the magazine to the wood screw above mentioned, and was fastened to both. When the wood screw was fixt to

be cast off from its tube, the magazine was to be cast off likewise by unscrewing it, leaving it hanging to the wood screw; it was lighter than the water, that it might rise up against the object to which the wood screw and itself were fastened.

"Within the magazine was an apparatus constructed to run any proposed length of time under twelve hours; when it had run its time it unpinioned a strong lock resembling a gun-lock, which gave fire to the powder. This apparatus was so pinioned that it could not possibly move till, by casting off the magazine from the vessel, it was set in motion.

"The skilful operator could swim so low on the surface of the water as to approach very near a ship in the night without fear of being discovered, and might, if he chose, approach the stem or stern above the water with very little danger. He could sink very quickly, keep at any depth he pleased, and row a great distance in any direction he desired without coming to the surface, and when he rose to the surface he could soon obtain a fresh supply of air. If necessary, he might descend again and pursue his course.

"After various attempts to find an operator to my wish, I sent one who appeared more expert than the rest from New York to a fifty-gun ship lying not far from Governor's Island. He went under the ship and attempted to fix the wooden screw in her bottom, but struck, as he supposed, a bar of iron which passes from the rudder hinge, and is spiked under the ship's quarter. Had he moved a few inches, which he might have done, without rowing, I have no doubt but that he would have found wood where he might have fixt the

screw, or if the ship were sheathed with copper he might easily have pierced it; but not being well skilled in the management of the vessel, in attempting to move to another place he lost the ship. After seeking her in vain for some time he rowed some distance and rose to the surface of the water, but found daylight had advanced too far that he durst not renew the attempt. He says that he could easily have fastened the magazine under the stem of the ship above the water, as he rowed up to the stern and touched it before he descended. Had he fastened it there the explosion of one hundred and fifty pounds of powder (the quantity contained in the magazine) must have been fatal to the ship. In his return from the ship to New York he passed near Governor's Island, and thought he was discovered by the enemy on the island. Being in haste to avoid the danger he feared, he cast off the magazine, as he imagined it retarded him in the swell, which was very considerable. After the magazine had been cast off one hour, the time the infernal apparatus was set to run, it blew up with great violence."

ROBERT FULTON'S EXPERIMENTS

The work begun by Bushnell in 1775 was taken up ten years later by Robert Fulton, whose diving boats so nearly fulfilled the conditions necessary for practical submarine navigation. As America was at peace at this time, and as her financial condition was at the lowest ebb, Fulton transferred his skill and energy to Europe which was then involved in the Napoleonic wars. Several attempts were made to interest the French

government in his invention, but altho certain commissions reported favorably on his ideas, nothing came of them for a time. In 1800, however, Fulton succeeded in interesting Napoleon in his scheme, and the following year he was given the opportunity of building his first submarine boat, the *Nautilus*. This boat was cigar-shaped, about twenty-one feet long and seven feet in diameter, and made of copper supported by iron ribs. When operating at the surface this boat used a peculiarly shaped sail; but when submerged it was propelled by a screw actuated by machinery turned by hand. In this boat, Fulton, with three companions, descended to a depth of twenty-three feet and remained submerged for twenty minutes; and at a depth of five or six feet they are said to have remained submerged for six hours, air being supplied by a copper vessel, probably containing oxygen or comprest air.

The first experiment made in attempting actually to destroy a vessel with the *Nautilus* was successful, a small vessel being sunk. Encouraged by this success Fulton proposed to build larger boats of this same type capable of destroying the largest battle-ships. In return he asked that a reward be paid him for each vessel destroyed, the price of his diving boat reimbursed and a patent be given himself and the members of his crew, so that in case of capture they would be treated as prisoners of war and not hanged as pirates. Strangely enough, this latter clause was the greatest stumbling-block, as the proposed methods of destroying battle-ships by torpedoes was held in such disrepute that the French government would not grant a patent rating the crew

of torpedo boats or submarine boats as legitimate belligerents. In effect, their attitude was that while a person was at liberty to destroy an empire from the surface of the water, he would be hanged as a criminal if he dived beneath the surface and destroyed a boat.

Discouraged by this stand of the French government, Fulton removed to England, where he succeeded in interesting the prime-minister, William Pitt, in his novel boat. A commission was appointed consisting of a number of prominent men, including Mr. Pitt, and Fulton was requested to demonstrate what could be done in actual practise by his submarine. On October 15, 1805, an old brig detailed for the purpose was destroyed by Fulton by the explosion of a torpedo containing one hundred and seventy pounds of powder. Yet in the face of this remarkable demonstration the commission remained unfavorable to Fulton's scheme, altho Mr. Pitt to the last retained his faith in the possibilities of such boats.

Recognizing that further attempts in England would be fruitless, Fulton returned to the United States. Here, in 1810, Congress became sufficiently interested to appropriate five thousand dollars to assist him in his work, and as a final test of the boat he had built, the naval authorities prepared the brig *Argus* to resist an attack by the submarine. This preparation consisted in surrounding her with protecting booms of logs, supporting strong netting, and held a distance from the hull by spars. In fact all possible means short of actually building a wall about the *Argus* were taken to defeat the attack. It is probable that the brig, when her preparations for

defense were completed, would have been invulnerable even to a modern torpedo, and it is not surprizing, therefore, that Fulton's attack upon her utterly failed.

Commenting upon this failure and the means taken by the authorities to protect the *Argus*, Fulton significantly remarked that the very fact that a war-vessel was obliged to make use of such means to protect herself against a system of attack, then in its infancy, spoke volumes for the possibilities of this method of attacking when it should be more fully developed.

But altho this failure to destroy the *Argus* caused Congress to withdraw its aid for future experiments in submarine warfare, Fulton himself never lost faith in the importance of his work. Even after his successful invention of the steamboat, for surface navigation, he is said to have remarked that, while this invention was important, it could in no wise compare with the revolutionary effects upon navigation that would eventually be produced by submarine boats. And despite his failure to convince the government of the possibilities of his diving boats, he continued his experiments with them. How nearly he succeeded in making a practical submarine was shown in the second war with England that followed soon after.

In this war a "diving boat," supposed to have been one of Fulton's submarines, made several attacks upon the British man-of-war *Ramillies* off New London, in the summer of 1813. In the first two attempts the approach of the submarine was detected by the crew of the man-of-war, who cut their cables, and stood out of the harbor as

quickly as possible. In the third attempt, the diving boat succeeded in coming up in a position directly under the *Ramillies*, fastened itself to the keel and made a hole in the planking large enough to receive the screw which was to fasten the torpedo in place. In the act of fastening it, however, this screw was broken off, and the attempt had to be abandoned for the moment.

This attack created such a panic aboard the British boat that she did not return to the inner harbor but kept constantly in motion outside. Not satisfied with this protection against "dishonorable attempts," the British commander took on board his vessel a hundred prisoners, apprizing the Americans of the fact, and assuring them that a similar action would be taken by all the ships of the British fleet, so that in case a vessel was torpedoed the American prisoners would be blown up with her crew. This effectually frustrated Fulton's plans; for when the fact became known in the United States, the Americans were naturally as vigorous as the British in protesting against Fulton and his boats.

Obviously the rule that "everything is fair in war" was not accepted in practise a hundred years ago. Fulton's attempts were regarded as the acts of a pirate, those of the British commander as perfectly legitimate and honorable methods.

A SUCCESSFUL DIVING BOAT

From the time of Fulton to the outbreak of the American Civil War there were few attempts at submarine navigation. On the opening of this war, however, efforts were made to perfect diving

boats; and these efforts were so well directed that eventually one of these boats succeeded in destroying the French boat *Housatonic* in Charleston Harbor on the night of February 17, 1864.

The submarine that accomplished this was one of the most remarkable boats ever constructed. It was cigar-shaped, about sixty feet long, and carried a crew of nine men. It was submerged partly by means of ballast tanks and partly by lateral fins. As a weapon it carried a spar torpedo fastened to its blunt nose. It was propelled by hand-power, eight of the nine members of the crew working on a crank which actuated the propeller. The ninth man, crouching in the bow, steered the boat. No reserve air was carried, and consequently the length of time the boat could remain submerged was limited to a very few minutes. On account of this, and because of its unfortunate career, it was aptly called the "peripatetic coffin;" and it justified this name by sinking five different times, drowning thirty-five out of forty of the members of its different crews. Nevertheless it succeeded in destroying an American war-vessel, thus demonstrating that this feat is possible under condition of actual warfare.

The submarines of the Civil War came to be known by the general name of "Davids," and several of them of different types were built. The only successful attack of any of these Davids, however, was the one which destroyed the *Housatonic*. In his book, *The Naval History of the Civil War*, Admiral Porter described this attack upon the *Housatonic* as follows:—

"At about 8.45 p. m. the officer of the deck on board the unfortunate vessel discovered some-

thing about one hundred yards away, moving along the water. It came directly toward the ship, and within two minutes of the time it was first sighted was alongside. The cable was slipt, the engines backed, and all hands called to quarters. But it was too late—the torpedo quarters. But it was too late—the torpedo mast, on the starboard side, in a line with the magazine. The man who steered her knew where the vulnerable spots of the steamer were, and he did his work well. When the explosion took place the ship trembled all over as if by the shock of an earthquake, and seemed to be lifted out of the water, and then sunk foremost, heeling to port as she went down.

"Her captain, Pickering, was stunned and somewhat bruised by the concussion, and the order of the day was 'Sauve qui peut.' A boat was despatched to the *Canandaigua,* not far off, and that vessel at once responded to the request for help, and succeeded in rescuing the greater part of the crew.

"Strange to say, the David was not seen after the explosion, and was supposed to have slipped away in the confusion; but when the *Housatonic* was inspected by divers, the torpedo-boat was found sticking in the hole she had made, and all her crew were dead in her. It was a reckless adventure these men had engaged in, and one in which they could scarcely have hoped to succeed. They had tried it once before inside the harbor, and some of the crew had been blown overboard. How could they hope to succeed on the outside, where the sea might be rough, when the speed of the David was not over five knots, and when

they might be driven out to sea! Reckless as it might be, it was the most sublime patriotism, and showed the length to which men could be urged on behalf of a cause for which they were willing to give up their lives and all they held most dear."

RECENT SUBMARINES AND SUBMERSIBLES

After the Civil War several nations interested themselves in the subject of submarines, and during the Franco-Prussian war in 1870-71, France attempted the construction of such vessels, but without success. Yet the possibility of producing these boats was becoming more apparent every year by the improvements in electrical motors, gasoline-engines, comprest-air motors, and the automobile- or fish-torpedo—itself a miniature submarine boat.

In America the progress made in submarine-boat construction has been fully as great, if not greater, than in any other country. Undoubtedly the foremost figure in this progress has been Mr. P. Holland; and his efforts and successes are largely responsible for the present fleet of submarine boats built already, or in the process of construction, as well as for those of several foreign countries. Indeed, in the matter of submarine inventions, only one country can be considered as rivaling America, that nation being France, whose enthusiasm for submarine navigation has been much greater than that of any other nation, altho in the matter of results she has not outstript the United States.

Mr. Holland's first submarine boat was built in

1857. It was called a "diving canoe," being only sixteen feet in length and wide enough to hold one man clothed in a diving-suit. Four years later, however, Holland built a large boat called the *Holland No. 3*, constructed along similar lines to the most recent submarines. This was the first buoyant submarine to be steered up and down by horizontal rudders alone, and may be said to mark an epoch in submarine navigation. But the *No. 3* had many defects and Mr. Holland continued to build and improve new boats until finally his ninth boat, which is the one familiarly known as the *Holland*, represented a practical form of submarine vessel. This boat was 53 feet 10 inches long, 10 feet 3 inches in diameter, had a displacement of 75 tons, and carried 10 tons of water ballast. The gasoline-engine which it used when running at the surface propelled the boat at the rate of seven knots an hour, and it could travel a distance of fifteen hundred miles at this rate of speed with the amount of fuel carried. When submerged it could run a distance of about fifty knots without coming to the surface.

In diving, the Holland type of boat takes in sufficient water ballast to lower it to the surface of the water. The horizontal rudders are then brought into use, causing it to descend to the desired depth, and keeping it at an approximately uniform distance from the surface while running submerged. By this arrangement the boat can dive very quickly, requiring only a matter of eight or ten seconds for reaching a depth of thirty feet. Record plunges have been made in less time than this.

The armament of the Holland boat was origi-

nally designed to consist of three tubes, two of which were for throwing aerial torpedoes and shells, and the third for discharging Whitehead torpedoes. One of these aerial guns was placed in the bow and one in the stern; but later the stern tube was abandoned. The bow gun was designed to discharge projectiles a distance of about one mile, such projectiles weighing something over two hundred pounds and carrying one hundred pounds of gun-cotton. The tube for discharging the Whitehead torpedo was practically the same as the submerged tubes in use at present on battle-ships.

Altho this *Holland* is now the type of diving boat most familiar to the majority of people, and the one in use in several navies, it should not be understood that the Holland boats were the only successful submarines constructed up to this time. France and Russia had produced successful diving boats; and in America those invented by Simon Lake, some of which are used for wrecking and salvage work as well as for war purposes, have proved quite as practical as the Hollands. In recent tests of these two types by the United States Government the Holland boats showed themselves to be slightly superior to the Lake boats in certain particulars, but the margin of superiority was a very narrow one.

The boats of the *Octopus* type are strictly speaking "diving boats," while the Lake boats are of the "even-keel" type. These terms refer to the method of submergence, the diving boats changing their horizontal trim when submerging, while the even-keel boats retain their horizontal trim, or nearly so.

The Lake boats have some features not usually embodied in other submarines, since some of the boats are designed for purposes other than warfare. Thus, they are equipped with wheels, or buffers, on which they can roll along the bottom of the ocean or bay. In the bow is an air-tight compartment with an opening in the bottom through which a diver can emerge and work on wreckage, or laying and disconnecting mines. These boats have also a safety device in the form of a detachable keel weighing several tons. In case of accident, when it might otherwise be impossible to rise to the surface, this keel can be detached simply by pulling a lever, thus giving the boat sufficient buoyancy to rise to the surface. This particular feature of the detachable keel is not peculiar to the Lake boats alone, some of the foreign submarines using a similar arrangement as a safeguard.

Technically speaking, the name "submarine" is now used only as applying to those boats that are operated solely by electric power, have little buoyancy, and do very little running at the surface. The term "submersible" is applied to a submarine boat, actuated by electricity while submerged, but using gasoline motors for motive power while running at the surface. These gasoline-engines are used at the same time for charging the storage batteries; so that the submersible is a much more practical boat than the submarine, and at the same time is quite as good a diver. Indeed, altho many naval writers are very careful to make a distinction in the use of these terms, there seems little need of doing so, since only one type of boat—the submersible—is now

considered practical. But as the word submarine is the older and more popular, it is used here to cover both classes except in specific cases.

For several years there were two classes of submarines under observation—those possessing no floatability when submerged and those having some reserve buoyancy. The advantage claimed for the no-floatability class of boats is that, having no buoyancy, they are kept more easily at a certain depth below the surface of the water instead of tending to come to the surface constantly as in the case of boats of the other type.

But in actual practise the theoretical possibilities of such boats have not come up to the expectations of their advocates. For keeping the boat at a uniform depth, the most universally accepted method is by the use of horizontal rudders. The fact that the vertical direction of a boat may be controlled by horizontal rudders, when her buoyancy is small, has long since been established in submarine navigation; and the simplicity of this method naturally helps its popularity. If there were no shifting of weight in a submarine, or no wave disturbance, it would not be difficult to set the rudders at such an angle that the boat would travel for long distances at an approximately uniform submergence, the depth of submergence being indicated by gages acted upon by the water pressure on the surface of the boat. And in actual practise it is possible to do this at the present time, part of the problem having been solved by automatic and other devices.

It should be remembered that many things enter into the disturbance of the submarine's equilibrium. The movement of a member of the

crew from one point to another shifts the ballast; a certain amount of leakage of water can not be avoided, and the sudden discharge of a torpedo weighing several hundred pounds from her bow tends to bring the boat quickly to the surface if this lost weight is not compensated for quickly. By various ingenious devices all these difficulties have been practically overcome, most of them automatically.

But the great unsolved problem of submarine navigation—practically the only one that now opposes a question-mark to its great utility in warfare—is that of steering with certainty of direction when submerged. Once the submarine is under water it is in utter darkness as far as seeing to steer is concerned; and what adds to the difficulty is the fact that the compass can not be relied upon, because of the surrounding electrical apparatus. It would be possible, perhaps, to construct a powerful electric lamp to throw a light some distance ahead of the boat, but this would defeat the primary object of submarine attack, as such a light would be seen by an enemy.

In still water, when the boat is running within a distance of ten or fifteen feet of the surface, it is possible to steer with great precision by the use of an optical tube or "periscope." This periscope is a straight, hollow tube, connected with the steering compartment in the submarine, and protruding above the water. In the upper end are a mirror and lenses so arranged that the surrounding objects are reflected downward through the tube, and show on a screen, or some other device, so that the helmsman sees things of exactly

the same size that they would appear to the naked eye. The periscope is also fitted with a telescope attachment which magnifies objects like the binoculars used in surface navigation. On some recent submarines there are two periscopes, a movable one for use of the commanding officer, and one that looks straight ahead for the helmsman's use.

In still water the periscope works admirably, but it is seriously interfered with even by small waves. It is so small and inconspicuous, however, that it might enable a submarine to creep within torpedo range even in daylight, and launch the torpedo with accuracy.

One great obstacle to successful submarine navigation on an extended scale is the difficulty of keeping a supply of air not only for the use of the crew, but for the engines. Any really powerful engine, either steam or gas, consumes an enormous amount of air. This is not true, of course, of the storage-batteries which furnish the power for running while submerged, but these, at best, are but feeble generators of energy, altho Edison's recent improvements may materially improve their power. If gasoline-engines could be used during submergence a far greater speed would be acquired; but this is out of the question, as such engines would consume the air supply of the little boat far too rapidly. The compromise, now adopted universally, is to use gasoline motors while running at the surface or partly submerged, when the conning-tower is open, utilizing part of their energy meanwhile to charge the storage-batteries.

It is evident, therefore, that no great speed can

be expected of the submarine in its present state; and in point of fact the largest type is able to develop only about ten or eleven knots when submerged, and fifteen while at the surface—far below the speed of any other type of war-vessel. But experimental attacks prove that they are dangerous fighting craft, and a recent voyage of thirteen hundred miles by a flotilla of Italian submersibles shows that such boats are no longer harbor-locked vessels.

Recently a British submarine flotilla, on a three-hundred mile trip, remained submerged for forty consecutive hours. The depth of the submergence in this case was only a few feet, but great depths may be reached with relative safety. In one test a Lake boat carrying her crew sank to a depth of one hundred and thirty-eight feet, returning to the surface in a few minutes. At another time the *Octopus*, without her crew, was lowered to a depth of two hundred and five feet, sustaining a pressure of fifteen thousand tons, without injury.

Such performances as these are thought-provocative, to say the least. Submarine boats that can hit the target without being detected, go on cruises unattended for more than a thousand miles, and remain submerged for more than a day and a half, must be classed as efficient engines of warfare.

Since the submersible is designed to spend most of its time on the surface of the water like an ordinary boat, it must have considerable buoyancy, but it must also have some means of getting rid of this buoyancy quickly when submergence is necessary. The submarine proper

has only from five to eight per cent. buoyancy, while some of the submersibles have twenty-five per cent. or more. With such boats of the ordinary size some fifty tons of water must be admitted before bringing them to a condition in which they can be submerged; but this can be done very quickly. One of the submarines of the U. S. fleet in an actual test filled her ballast tanks and dived to a depth of twenty feet in four minutes and twenty seconds.

It is not impossible that the recent triumphs in aerial navigation may have an important bearing on the use of submarines in future wars. It is well known that large objects when submerged even to a considerable depth are discernible from a height in the air directly above them. It is quite possible, therefore, that swift aeroplanes circling about a fleet of war-vessels might be able to detect submarine boats when these boats were near enough the surface to use their periscopes. If so it might be possible for the aeroplanes to drop torpedoes upon the submerged boats without danger to themselves. Or if the aeroplanes carried no effective weapons, they could at least act in the capacity of scouts and warn their battleship consorts of the presence of the submarine. Of course, this would be possible only in daylight, the air-ships giving no protection against night attacks.

IV

THE STEAM LOCOMOTIVE

Modern railroads are the outcome of the invention of the locomotive; yet the invention of the practical locomotive was the outcome of iron railroads which had been in existence for half a century. These iron railroads were a development from wooden predecessors, which were the direct descendants of the smooth roadways of the Greeks and Romans. Indeed, it is quite reasonable to suppose that the ancients may have been familiar with the use of parallel rails with grooved flanged wheels to fit them; but if so there seems to be no definite record of the fact, and our knowledge of true railroads goes back only to the seventeenth century.

As early as 1630, it is recorded that a road built of parallel rails of wood upon which cars were run was used in a coal-mine near Newcastle, England; and there is no reason to suppose that this road was a novelty at the time. Half a century later there was a railroad in operation near the river Tyne which has been described by Roger North as being made of "rails of timber placed end to end and exactly straight, and in two parallel lines to each other. On these rails bulky cars were made to run on four rollers fitting the rails, whereby the carriage was made so easy that one horse would draw four or five chaldrons of coal to a load."

At this time the use of iron rails had not been thought of, or at least had not been tried, probably from the fact that iron was then very expensive. Even the wooden rails in use, and the wheels that ran upon them, were of no fixed pattern. Some of these rails were in the form of depressed grooves into which an ordinary wheel fitted. But these were very unsatisfactory be cause they became filled so easily with dirt and other obstructions, and a more common type was a rail raised a few inches above the ground like a molding, a grooved wheel running on the surface.

Such rails were short-lived, splitting and wearing away quickly, and being easily injured by other vehicles. But they were, on the whole, more satisfactory than the deprest rails, and were the type adopted when iron rails first came into use, about 1767. Ten years later the idea of the single flange was conceived, not placed on the wheels of the cars as at present, but cast on the rails themselves. These flanges were first made on the outside of the rails, and later placed on the inside, the wheels of the cars used on such rails being of the ordinary pattern with flat tires.

But, in 1789, William Jessop, of Leicestershire, began building cars with wheels having single flanges on the inside like modern car-wheels, to run upon an elevated molding-shaped iron rail; and the many points of superiority of this type of wheel soon led to its general adoption. So that aside from some minor changes, the type of rails and wheels in use at the close of the eighteenth century was practically the same as at present.

It is probable that if the first inventors had attempted to make locomotives to run upon the railroads then in existence they would have been successful many years before they were, but the advantages of railroads was not evident then as now, and the inventors' efforts were confined to attempts to produce locomotive wagons—automobiles—to operate upon any road where horses and carts could be used.

Some of their creations were of the most fanciful and impractical design, altho quite a number of them were "locomotives" in the sense that they could be propelled over the ground by their own energy, but only at a snail's pace, and by the expenditure of a great amount of power. Several inventors tried combining the principle of the steamboat and the locomotive in the same vehicle, and in 1803 a Philadelphian by the name of Evans made a steam-dredge and land-wagon combined which was fairly successful in both capacities of boat and wagon. He called his machine the "Oruktor Amphibious," and upon one occasion made a trip through the streets of Philadelphia, and then plunged into the Schuykill River and continued his journey on the water. But as he was unable to arouse anything but curiosity, the financiers refusing to take his machine seriously, he finally gave up his attempts to solve the problem of steam locomotion.

The year before this, in 1802, Richard Trevithick, in England, had been more successful in his attempts at producing a locomotive. He produced a steam locomotive that operated on the streets of London and the public highways, hauling a wagon-load of people. But the unevenness

of the roads proved disastrous to his engine, and as it could make no better time than a slow horse, it was soon abandoned. But Trevithick had learned from his failure that a good roadbed was quite as essential to the success of a locomotive as the machine itself, and two years later he produced what is usually regarded as the first railway locomotive. This was built for the Merthyr-Tydvil Railway in South Wales, and on several occasions hauled loads of ten tons of iron at a fair rate of speed. It was not considered a success financially, however, and was finally abandoned.

At this time a curious belief had become current among the inventors to the effect that if a smooth-surface rail and a smooth-surface wheel were used, there would not be sufficient friction between the two to make it possible to haul loads, or more than barely move the locomotive itself. Learned mathematicians proved conclusively on paper by endless hair-splitting calculations that the thing was impossible,—that any locomotive strong enough to propel itself along a smooth iron rail would be heavy enough to break the strongest rail and smash the road-bed. In the face of these arguments the idea of smooth rails and smooth wheels was abandoned for the time. Trevithick himself was convinced, and turned his attention to the perfecting of an engine with toothed drive-wheels running on a track with rack-rails. But this engine soon jolted itself and its track into the junk-heap without doing anything to solve the problem of locomotion.

Shortly after this, a man named Chapman, of Newcastle, built a road and stretched a chain

from one end to the other, this chain being arranged to pass around a barrel-wheel on the locomotive, which thus pulled itself along, just as some of the boats on the Rhine do at the present time. But the machinery for operating this engine was clumsy and unsatisfactory, and the road proved a complete failure.

Perhaps the most remarkable locomotive ever conceived and constructed was one built by Brunton, of Derbyshire, in 1813. This machine was designed to go upon legs like a horse, and was a combination of steam wagon and mechanical horse. The wagon part of the combination ran upon a track like an ordinary car, while the mechanical legs were designed to trot behind and "kick the wagon along." "The legs or propellers imitated the legs of a man or the forelegs of a horse, with joints, and when worked by the machine alternately lifted and prest against the ground or road, propelling the engine forward, as a man shoves a boat ahead by pressing with a pole against the bottom of a river." This machine was able to travel at a rate somewhat slower than that at which a man usually walks; and its tractive force was that of four horses. But after it had demonstrated its impotency by crawling along for a few miles, it terminated its career by "blowing up in disgust," killing and injuring several bystanders.

The much-disputed point as to whether a smooth-wheeled locomotive would be practical on smooth rails was not settled until 1813. An inventor named Blackett, of Wylam, who with his engineer, William Hedley, had built several steam locomotives which only managed to crawl

along the tracks under the most favorable conditions, wishing to determine if it were the fault of locomotives of the system on which they worked that accounted for his failures, constructed a car which was propelled by six men working levers geared to the wheels, like the modern hand-car.

In this way he determined that there was sufficient adhesion between smooth rails and smooth wheels for locomotives to haul heavy loads behind them, even on grades of considerable incline. The experiments of Blackett settled this question beyond the possibility of controversy, and removed a very important obstacle from the path of future inventors. Among these inventors was young George Stephenson, who was rapidly making a reputation for himself as a practical engineer.

STEPHENSON SOLVES THE PROBLEM

Stephenson was born on June 9, 1781, in the small colliery village of Wylam, on the river Tyne. His parents were extremely poor, and as the boy was set to work as soon as he was large enough to find employment of any kind, he was given no education, even to the extent of learning the alphabet. It was only after he had spent many years in the colliery and had finally worked himself up from the position of "picker" at threepence a day to that of fireman, that he was able to spend the necessary time and pennies to acquire something of an education. Then he attended a night-school, learned his alphabet, was able to scrawl his name at eighteen years of age,

and a little later could read, write, and do sums in arithmetic.

But if deficient in letters, there was one field in which he had no superior,—that was in the practical handling of a steam-engine. His position in the mine gave him a chance to study the workings of the engines then in use, and at every opportunity, on holidays and after working-hours, he was in the habit of dismantling his engine, and carefully studying every detail of its construction. Thus by the time he had reached his majority he was a skilful engineer, besides having many new ideas that had developed during his examinations of the machinery. But, besides his knowledge of engineering, he was an accomplished workman in other fields. He was a good shoemaker, watch- and clock-repairer, and tailors' cutter, at all of which trades he worked at odd times to increase his income. Thus he was a veritable jack-of-all-trades, with the unusual qualification that he was master of *one*.

By the time he was twenty-six years old he was holding the position of engineer to a coal-mining company, and had acquired the confidence of his employers to such an extent that he was permitted to build a locomotive for them—a thing that had been his ambition for several years. This was in 1807, the same year that Robert Fulton demonstrated the possibilities of steam navigation.

In the construction of this engine Stephenson introduced several novel features of his own inventing, altho on the whole no new principles were involved; and in practise this engine showed several points of superiority over its predeces-

sors. It would draw eight loaded wagons of thirty tons' weight at the rate of four miles an hour on an ascending grade of one in four hundred and fifty feet. But it had two very radical defects—it would not keep up steam and the noise of the steam-pipe exhausting into the open air frightened the horses of the neighborhood to such a degree that the authorities ordered the inventor either to stop running his engine or suppress its noise. As an experiment, therefore, Stephenson arranged the exhaust pipes so that they opened into the smokestack, where the sound would be muffled. But when the engine was now tried he found to his surprize that this single expedient had solved both difficulties, the exhausting steam causing such an improvement in the draft of his furnace that double the quantity of steam was generated. This discovery helped to simplify later experiments, for the difficulty of keeping up steam had been one of the great obstacles encountered by the inventors.

Stephenson's second locomotive was an improvement over his first in many ways, but it was still far from being the practical machine that was to supplant horse-power. It could haul heavier loads than teams of horses, and was more convenient for certain purposes; but it was no more economical.

As yet the only use to which locomotives had been put was that of hauling cars in coal-mines. Indeed, the only railroads then constructed were those used in mines, the idea of utilizing such roads for passengers and freight traffic not having occurred to any one until about 1820. Then the Englishman, Thomas Gray, suggested the con-

struction of such a road between Liverpool and Manchester, advocating steam as the motive power. His idea was looked upon as visionary, and as he persisted in his efforts to interest prominent people in the scheme, he came to be very generally regarded as an enthusiastic but somewhat crack-brained fanatic.

But meanwhile the coal railroads were being extended to such lengths that they were assuming the proportions of modern railroads. The motive power on most of the roads was horses, altho here and there a traction engine using chain or cable was employed for certain purposes. In 1825, however, Stephenson began the construction of an improved locomotive, this time at his own modest establishment; and a little later this engine made the trial that really demonstrated the possibilities of steam locomotion, altho this was not universally recognized until the success of the *Rocket* a few years later.

A great deal of excitement and speculation arose throughout the country when the trial day approached. Great crowds assembled from every direction to witness the trial; some, more sanguine, came to witness the success, but far the greater portion came to see the bubble burst. The proceedings began at Busselton incline, where the stationary engine drew a train up the incline on one side and let it down on the other. The wagons were then loaded.

"At the foot of this plane a locomotive, driven by Mr. Stephenson himself, was attached to the train. It consisted of six wagons loaded with coal and flour, next a passenger coach (the first *ever run* upon a railroad) filled with the directors

and their friends, then twenty wagons fitted up with temporary seats for passengers, and lastly came six wagons loaded with coal, making in all twenty-eight vehicles. The word being given that all was ready, the engine began to move, gradually at first, but afterward, in part of the road, attaining a speed of twelve miles an hour. At that time the number of passengers amounted to four hundred and fifty, which would, with the remainder of the load, amount to upwards of ninety tons. The train arrived at Darlington, eight and three-quarter miles, in sixty-five minutes. Here it was stopt and a fresh supply of water obtained, the six coal-cars for Darlington detached, and the word given to go ahead. The engine started, and arrived at Stockton, twelve miles, in three hours and seven minutes, including stoppages. By the time the train reached Stockton the number of passengers amounted to over six hundred."

From this description it will be seen that the coal roads had been extended to form interurban railways. In this connection it is interesting to note the increase of traffic that developed on this particular road in the years immediately following the invention of the practical locomotive. When the road was projected it was estimated that its maximum carrying capacity would not exceed 10,000 tons of coal yearly. A few years later, when locomotives had come into use, the regular yearly carriage amounted to 500,000 tons.

The passenger coach on this first train, the first of its kind ever constructed for the special purpose of carrying passengers, was remarkable for its simplicity. One writer described it as "a

modest and uncouth-looking affair, made more for strength than for beauty. A row of seats ran along each side of the interior, and a long table was fixt in the center, the access being by the doorway behind, like an omnibus. This vehicle was named the *Experiment,* and was the only carriage for passengers upon the road for some time."

About this time the now famous Liverpool and Manchester Railway was projected. It was elaborately planned and carried out at an enormous expense. The construction of the road-bed was given special attention, altho as yet the question of what motive power should be used had not been decided. Most of the directors and engineers favored the use of horses. The few that were in favor of steam did not favor the use of locomotives, but a system that would now be called a relay-cable system. According to this plan the road of about thirty miles was to be divided into nineteen sections, over each of which a stationary steam-engine was to work a chain or cable. But when the board of engineers appointed to investigate the possibilities of this system reported on the matter, it was found that there were several vital defects in such a system. For example, should any one of the sections of cable break or become inoperative, the entire line would have to stand idle; and furthermore, the cost of building and maintaining these nineteen stations offered serious financial obstacles.

It is an interesting fact that until the report of this board was made "not a single professional man of eminence could be found who preferred *the locomotive* over the fixt engine, George

Stephenson only excepted." But with the glaring defects of the cable road, and the enormous cost of maintenance imprest upon the directors, the idea of the locomotive became at once more attractive, and the performance of Stephenson's locomotive was more carefully investigated. The upshot of these investigations was the offer of a prize of £500 for a locomotive that on a certain day would perform certain duties as follows:—

1. The engine must effectually consume its own smoke.

2. The engine, if of six tons' weight, must be able to draw, day by day, twenty tons' weight, including the tender and water-tank, at ten miles an hour, with a pressure of steam upon the boiler not exceeding fifty pounds to the square inch.

3. The boiler must have two safety-valves, neither of which must be fastened down, and one of them completely out of the control of the engineer.

4. The engine and boiler must be supported upon springs and rest on six wheels, the height of the whole not exceeding fifteen feet to the top of the chimney.

5. The engine with water must not weigh more than six tons, but an engine of less weight would be preferred, altho drawing a proportionately less load behind it; if only four and one-half tons it might be put on four wheels.

6. A mercurial gage must be affixt to the machine, showing the steam pressure about forty-five pounds to the square inch.

7. The engine must be delivered, complete and ready for trial, at the Liverpool end of the railway, not later than October 1, 1820.

8. The price of the engine must not exceed £550.

What strikes one as most peculiar in this set of requirements and specifications is the first clause—that of the engine consuming its own smoke; for even at the present time this is considered a difficult problem. But this was not so considered by the inventors of that time, their great stumbling-block being the high speed required. Ten miles an hour struck most of them as absurd and out of the question.

One eminent person, who was to become later one of England's leading engineers, stated publicly that "if it proved to be possible to make a locomotive go ten miles an hour, he would undertake to eat a stewed engine-wheel for his breakfast." It is not recorded whether or not this terrible threat was carried out.

But there was more than one engineer and engine-builder who took a more sanguine view of the prize offer. The firm of Braithwait & Ericsson signified its intention of competing with a locomotive that they named the *Novelty*. Another firm entered the contest with an engine called the *Sans-pareil*; still another firm entered the *Perseverance*; and George Stephenson was on hand with the now famous *Rocket*.

In the series of trials that followed the *Sans-pareil* and the *Perseverance* were so clearly outclassed by the other two competing locomotives that they need not be considered here; but the *Novelty* and the *Rocket* were close competitors. The *Novelty* indeed made such a good showing, and afterwards proved to be such a good locomotive, that altho it lost the contest, many com-

petent judges have since regarded it as equal to the *Rocket,* if not superior, in principle. Be that as it may, later experiments proved conclusively that the cause of failure on the final day of the prize contest was due to defects in workmanship rather than to defective principles of construction.

The *Novelty* has been described as having the appearance of a "milk-can set in the rear of a wagon, with a little smokestack in front looking like a high dashboard." It carried its supply of fuel and water in the "wagon-box" part of the engine frame, in front of the boiler, so that it required no tender. On its first trial, running without any load, it reached a speed of twenty-four miles an hour—a speed more than double the "stewed engine-wheel" limit. But at each subsequent trial, altho it hauled loads for short distances, some part of its machinery became disabled, so that it was necessarily regarded as inferior to its more stable rival, the *Rocket.*

The *Sans-pareil* was considerably over the maximum weight and according to a strict interpretation of the stipulations, should not have been allowed to contest; but altho this question of overweight was waived by the judges, and the engine given a fair trial, it showed such a capacity for consuming fuel without any corresponding ability to perform work, that it was decided inferior to the *Novelty* and the *Rocket.* The *Perseverance* was clearly outclassed by all the other competing engines, as its maximum speed was only five or six miles an hour.

The most consistent performer, and the final prize-winner, as every one knows, was Stephen-

son's *Rocket*, the direct ancestor of all modern locomotives. The boiler of this locomotive was horizontal, as in modern locomotives, cylindrical, and had flat ends. It was six feet in length and a little over three feet in diameter. The upper half of the boiler was used as a reservoir for steam, the lower half being filled with water and having copper pipes running through it. The fire-box, two feet wide and three feet high, was placed immediately behind the boiler. Just above this, and on each side, were the cylinders, two in number, acting obliquely downward on the two front wheels of the engine, the piston-rod connecting with the driver by a bar pinned to the outside of the wheel, as in modern American locomotives.

The engine with its load of water weighed a trifle over four tons—seemingly little more than a toy-locomotive, as compared with the modern monsters more than thirty times that weight. But for its size the little *Rocket* was a marvelous performer, even as judged by recent standards. On the first day of the contests over the two miles of trial tracks, it covered twelve miles in considerably less than an hour, shuttling back and forth over the road. The next day, as none of the other engines was in condition to exhibit, Stephenson offered to satisfy the curiosity of the great crowd that had gathered—a crowd that contained representatives from all over the world—by an unofficial trial of the *Rocket*. He coupled the little engine to a car, loaded on thirty-six passengers, and took them for a spin over the road at the rate of from twenty-six to *thirty* miles an hour.

The following day some of the competing locomotives were still unable to exhibit, and again the *Rocket* was given a semi-official trial. Hauling a car loaded with thirteen tons' weight, it ran back and forth over the two-mile road, covering thirty-five miles in one hour and forty-eight minutes, including stoppages. The maximum velocity attained was about twenty-nine miles an hour. As this performance was duplicated on the day of the official trial, the *Rocket* was declared the winner, and awarded the prize.

Naturally there were many minor defects in the construction of this first locomotive, altho most of them were too trivial and unimportant to affect the excellence of the machine as a whole. But it had one serious defect: the inclination of the cylinders caused the entire machine to rise and fall on its springs at every double stroke, producing great unsteadiness when running at any considerable speed. This was corrected a few months later by the suggestion of Timothy Hackworth, who drew plans for a locomotive having horizontal cylinders to be used on the Stockton and Darlington Railway. His plans were submitted to Stephenson, who constructed an engine from them called the *Globe,* which differed from the *Rocket* in having the cylinders not only horizontal, but placed on the inside of the wheels. A little later Stephenson built the *Planet* on much the same lines as the *Globe,* and this engine became the model for engine builders the world over. It is an interesting fact that American engineers adopted, and still cling to, Stephenson's original plan of having the cylinders act on rods attached to the

outside of the wheels as in the *Rocket*, while English engineers have always built their locomotives with the cylinders on the inside, as arranged on the *Planet*.

Since the time of the *Planet* the general shape and arrangement of most locomotives has remained unchanged. In America the inclemencies of the climate compelled the invention of the cab; and it was here also that the bell, whistle, pilot, and sand-box were first introduced. But by 1850 the present type of locomotive had been produced; and altho constant modifications are being introduced, the general appearance of the locomotive remains the same, the difference being mostly in the bulk.

IMPROVEMENTS IN LOCOMOTIVES IN RECENT YEARS

During the closing years of the nineteenth century the general improvements in the rolling-stock of railroads, and the constantly increasing demand for faster passenger service, stimulated manufacturers to attempt numerous improvements as well as many changes in the size of the more recent types of locomotives. In a general way these changes may be summarized as follows: A great increase in the size and weight, with increased speed and tractive power; the use of larger boilers with thicker shells; the substitution of steel for cast iron in certain parts of the locomotive, thereby greatly increasing the strength; and finally, the economizing of steam by compounding.

There is no way of determining the exact amount of increase in the weight of engines

during the last decade, but the figures of some of the great manufacturing establishments will give a fair idea of this increase in a general way. In one of these establishments the average weight of a locomotive turned out ten years ago was 92,000 pounds for the engine alone, without the tender. At the present time the engines being manufactured by the same firm average 129,000 pounds, an increase of 37,000 pounds, or something over forty per cent. This average weight, however, gives but an inadequate conception of the size of the largest locomotives now being manufactured. The "hundred-ton" engine has become a commonplace. In 1909 a locomotive weighing, with its tenders, 300 tons was manufactured for passenger traffic on the Santa Fé lines.

In America there seems to be no limit to the sizes that may be reached; or at least up to the present time this limit has not been attained. In England and several of the Continental countries a great difficulty has been found to exist in the unlimited size of locomotives, in the fact that the bridges and tunnels of these railroads are, almost without exception, so low that any very great vertical increase in the size of the engine is out of the question without reconstructing many miles of bridges and tunnels at an enormous cost.

The increased demand for greater speed has also caused a marked increase in the amount of steam pressure per square inch in the boilers. In 1870 the average was about 130 pounds; by 1890 this had been increased to about 160 pounds; while at the present time steam is used to

quently at a pressure of 225 pounds. Naturally this increase in pressure compels the use of heavier steel boiler-plates. In 1890 the usual thickness of the steel sheets was one-half inch; but at the present time it is no unusual thing to use plates seven-eighths of an inch in thickness.

But probably the most important improvement in locomotive construction in recent years is the introduction of the compounding principle in the use of steam—a system whereby practically the entire energy of the steam is utilized, instead of a considerable portion of it being a dead loss, as in the older type of engine. As every one knows, the passage of the steam through a single cylinder of an engine does not exhaust its entire energy. In the compounding system this exhausted steam is made to pass through one or more cylinders after coming from the first, the energy of all these cylinders being utilized for the production of power.

The application of this principle of compounding is not new even in the field of locomotive construction. As early as 1846 patents for a compound locomotive were taken out in the United States, and such an engine built in 1867; but it is only since 1890 that compound locomotives have become popular in this country. In these compound locomotives the two cylinders are of unequal diameter, so proportioned "that the steam at high pressure in the smaller cylinder exerts upon the piston approximately the same force that is exerted by steam at a lower pressure in the larger cylinder. Steam is admitted first into the smaller cylinder, where it expends *a portion* of its initial energy, and then passes

into the larger cylinder, where it performs an equal amount of work by exerting a diminished pressure upon a larger surface. This is the principle of compounding, the relative sizes and positions of the cylinders being varied according to the conditions to be met by the engine, or the ideas of the designer or builder, or of the purchaser. While in the marine and stationary engine the compound principle has been carried with success and economy to three and four stages of expansion in the use of steam, it has not been found practicable to go beyond two stages in compound locomotives."

Of course, the principal reason for compounding the locomotive is to economize steam, and this is unquestionably accomplished; but nevertheless the comparative economy of compound and single-expansion locomotives was for some time a mooted question. Numerous tests have been made with these two classes of engines, and the widest ranges of differences were shown in many instances. In some cases the compounds seem to show a saving of some forty per cent. in fuel; but this is by no means a determinable factor in the daily use of an engine. It is found that repairs on the compound are more difficult to make, and consequently more expensive than on the single-expansion engines; but on the whole it is very generally conceded that the compound saves its owners from ten to twenty-five per cent. over the older type.

The rapid increase of the size, and consequent coal-consuming capacity, of the modern locomotive has added another problem to engineering—that of keeping the yawning maw of the fire-box

supplied with coal. There is a limit to the amount of work that the fireman can do, and the great engines in use at present tax even the strongest fireman to the utmost. If the size and speed of locomotives is increased very materially in the future it will be necessary to have two men, instead of one, as firemen, or to use mechanical stokers, or to find some other kind of fuel. In point of fact the mechanical stoker has been recently tried with success, and this will probably help in solving the problem. But there is also the strong probability that the use of liquid fuel will become more and more popular. At the present time many locomotives in the West and Southwest, as well as in Europe and in Asia, have been equipped with burners for the consumption of crude petroleum. No modification in the construction of the locomotive is required for this change of fuel except some slight alteration in the arrangement of the brickwork of the fire-box and the introduction of the burners. These, however, are simple arrangements that throw into the fire-box a spray of steam and vaporized oil, which burns freely and generates an intense and steady heat. With this kind of fuel the fireman need not be considered, as the largest engine thus equipped may be "fired" with far less labor than is required on the smallest coal-burning, narrow-gage locomotive.

THE WESTINGHOUSE AIR-BRAKE

The application of steam as a motive power for running trains of cars solved one great problem; but it created another. The second one was the

problem of how to stop the trains once they had started. On short trains made up of the light cars used at first, the hand-brakes were sufficiently effective for practical purposes. But as trains were increased in length and weight and were run at high speeds, it became imperative to find some means of stopping such trains quickly and with certainty.

With a hand-brake working on each pair of trucks, as on passenger coaches, it was possible to make reasonably quick stops when there were enough members of the train crew to work all the brakes simultaneously. But in practise it was found impossible to maintain this ideal condition. For emergency stops the brakemen were summoned by signals of the whistle given by the engineer, and there was necessarily some little interval of time after this signal before the most alert crew could begin the relatively slow process of applying the brakes.

The engineer himself could give valuable aid in stopping the train by reversing his engine, the locomotive acting as a brake to check the oncoming cars. But this check acted only at the forward part of the train, and being applied suddenly caused the rear cars to rush against the forward cars with terrific force, sometimes driving in the bumpers and wrecking the train. Obviously an ideal system of brakes must be one that acted upon all the cars of the train simultaneously and under control of the engineer; and presently such a system was invented by Mr. George Westinghouse.

Other inventors had tried to produce a practical system of brakes, such as those using

steam as a working force, or systems of hand-wound springs; but Mr. Westinghouse utilized compressed air, and from the first his brakes proved effective.

His first air-brake, operated successfully in 1869, was the "straight air-brake" type—one that has now been replaced almost universally by the automatic. In this brake system there was an air reservoir on the locomotive, and steam was used for making the compression. From this reservoir a line of gas-pipe ran through the cab of the engine beneath the tender and under each car, the space between the cars being bridged by rubber tubes and easily-adjusted couplings. This line of pipe, called the train pipe, was connected near the center of each car with a cylinder which contained a piston with a stem which acted upon the brake-shoes by means of a series of levers and connecting rods.

In the cab, placed conveniently for the engineer, was a valve by means of which he could cause the compressed air to flow into the train pipe and thus act upon the brake cylinders of the cars. This could be done gradually for making a slow stop, or with full force as the case required, and the brakes could be released by turning the valve to a point which opened a vent and allowed the air to escape.

The effect of this invention was revolutionary. Stopping the train was no longer dependent upon manual labor applied intermittently at different points, but was placed entirely in the hands of the engineer who applied the required power almost simultaneously at all points along his line of cars. Thus the brakeman was relieved of one

of his perilous tasks, which on freight-trains took a heavy toll in loss of lives.

This relatively simple, and usually effective, system had two grave defects. The first of these lay in the fact that if there was a leak—even a very small one—anywhere along the line of the train pipe or the brake cylinders, the brakes would not work, the comprest air being exhausted into the atmosphere instead of acting on the brake cylinders. The common accident of having his train "break in two" rendered the engineer powerless to stop the cars, and disastrous "runaways" sometimes resulted. The second defect, which became more and more apparent as the length of trains was increased, was the impossibility of applying the air to the brakes of the rear cars as quickly as to those near the engine, since the comprest air could not travel the length of the train pipe instantaneously, on account of the frictional resistance.

These defects were quickly recognized by Mr. Westinghouse, and in 1876, seven years after he applied his first invention, he produced his automatic air-brake which overcame them effectually. In this brake the train pipe and the air reservoir were retained as in the straight air-brake system, but in addition each car was equipped with a storage reservoir of sufficient size to supply the brake cylinder. In place of the older arrangement in which the train pipe simply retained air at atmospheric pressure when not in use, the new system kept the air in the train pipe under a considerable pressure at all times when the brake was not in use. And, reversing the conditions of the straight air-brake the engineer in order to

apply the brakes let out the air in the train pipe instead of forcing air into it, a "triple valve" on each car performing the work of operating the brake cylinder automatically.

The advantage of this system over the older one is obvious. Whereas the detachment of a portion of the train, or a leak in any part of the air-brake system, heretofore had left the engineer helpless, exactly the reverse condition was produced in the new system. Any leakage of air, either from a break or a defect, caused every brake on the entire train to be applied to the wheels and brought the train to a stop. Moreover, with the new system it was now possible to equip each car with a valve which would lessen the pressure of air in the train pipe so that the train could be brought to a stop by the trainmen in the rear or intermediate coaches as readily as by the engineer.

This system worked perfectly on passenger trains; but on long freight-trains the resistance to the passage of the escaping air through the train tube was so great that if an emergency required the full force of the brake to be applied suddenly, the brakes of the rear cars did not come into use until several seconds after those of the forward cars. The result was that the momentum of the rear cars caused them to strike the forward cars with great violence. But Mr. Westinghouse overcame this defect by an ingenious use of the triple valve mechanism of each car, whereby the application of the emergency brake by the engineer caused the air in the train pipe on each car to be discharged simultaneously into the brake cylinder. In this manner the dis-

charge of air not only allowed the brakes to act, but assisted them in doing so. This was only the case, however, when the emergency application of the brake was made, this system of venting on each car into the brake cylinder not being brought into play when ordinary stops were made. Thus the engineer in this quick-action automatic air-brake has really two brakes at his command, one for making ordinary stops, the other for emergencies.

In 1891 a so-called high-speed air-brake was perfected, this brake being really a modified quick-action automatic brake. This modification consists of the addition of an automatic pressure-reducing valve connected with each brake cylinder. In the high-speed air-brake as applied when the train is running rapidly, the highest possible pressure is applied at once to the wheels, but this pressure is lessened by the automatic pressure-reducing valves as the speed diminishes. This method of applying the brakes is the most effective way of getting the full benefit of their stopping power. This high-speed brake, therefore, represents the highest perfection in train-stopping devices.

We have referred here specifically to the air-brake as used on steam railroads. In another chapter the subject has been touched upon in connection with electric railroads. In such brakes the compression of the air is accomplished by electricity instead of steam, but the general principles involved are the same as those just described.

It should not be understood that the Westinghouse air-brake was the only one, or the only

type of brake devised and brought to practical perfection. For a time a vacuum brake, which utilized atmospheric pressure, offered keen rivalry. But eventually the type of brake perfected by Mr. Westinghouse, modified in certain details in the various countries of Europe and America, gained precedence, which it still retains.

AUTOMATIC COUPLINGS

The perfection of the air-brake removed one great source of danger that menaced the crews of freight-trains. There still remained another almost as great, particularly in the matter of maiming its victims, when not actually killing them. This was the old method of coupling freight-cars as practised in America. There were few old-time trainmen, indeed, who could show a complete set of full length digits, the buffers of the old-fashioned couplings being responsible for the lost and shortened members.

The freight brakeman has to make scores of couplings on every trip. And he literally took his life in his hands upon each and every occasion of making a coupling by the old method.

This old form of couplings consisted of two buffers—one on each car—joined together by an iron link about fifteen inches long, a movable pin inserted at either end holding the link in place and thus joining the cars. When a coupling was to be made the brakeman raised the pin in the buffer of the stationary car and tilted it at an angle in the pin-hole at the top of the buffer so that, while it remained raised, the jar of the striking buffers at the moment of coupling caused

it to fall into place and complete the coupling. The link was left hanging in the moving car which was being shunted in to be coupled; but in the position of the projecting end was so low that it would miss the hole in the opposite buffer, and thus fail to make the coupling, unless raised and inserted just at the moment before the buffers came together.

This raising and inserting of the link was the dangerous part of making a coupling. It could only be done by the brakeman while standing between the cars. And he must raise the link, insert it, and remove his hand in a fraction of a second if the car was moving at a fair rate of speed, otherwise his fingers or hand would be caught between the buffers and crushed. And a crushed hand or arm meant subsequent amputation, for the force of the collision between the buffers crushed the bones beyond repair.

There was a way in which the coupling could be made whereby the hand was not endangered. This was by using a stick for raising and guiding the link into the buffer. Some railroads at first furnished sticks for this purpose. But no brakeman would stoop to use them. Had he done so he would have been hooted and jeered off the road by his train-mates. And so his pride made him risk his limbs and his life, and fostered the recklessness of the old-time brakeman.

But in 1879, Mr. Eli Janney, of Pittsburg, patented an automatic car-coupler that was both simple and effective; and in 1887 the Master Car Builders' Association accepted this type of coupler. A little later the U. S. Government, influenced by the appalling loss of life among the

brakemen, passed laws compelling all cars to be equipped with some form of automatic coupling device, and naturally the Janney coupling was the one adopted. In using this coupling the brakeman did not have to step into the dangerous position between the cars, either for making the coupling or disconnecting the car. The act of coupling was done automatically, while the uncoupling was effected by the use of a lever operated from the side of the car.

Even before the invention of the Janney couping a semi-automatic coupling device had been used extensively on passenger cars. But this device, which in effect was that of two crooked fingers hooked together, allowed the ends of the coaches to swing and roll in a manner most disagreeable to many passengers. The Janney couplings corrected this, since these couplings in their improved form hold the ends of the cars as in a vise.

A COMPARISON—THE OLD AND THE NEW

Stephenson's locomotive and its tender, when loaded to full capacity with fuel and water, weighed seven and three-quarter tons. The locomotive itself was a trifle over seven feet long. In 1909 the Southern Pacific Railway purchased a Mallet Compound locomotive which, with its tender, weighs three hundred tons, or approximately forty times the weight of the little *Rocket*. This great locomotive is over sixty-seven feet long, or some nine times the length of the *Rocket*, and will haul more than twelve hundred tons back of the tender.

The cylinders of the *Rocket* were eight inches in diameter, with a seventeen-inch stroke; the high-pressure cylinders of this Mallet locomotive are twenty-six inches in diameter, and the low-pressure cylinders are forty inches. But curiously enough the driving-wheels of the two engines show little discrepancy, those of the *Rocket* being fifty-six inches in diameter, as against fifty-seven for those of the larger engine. The total heating surface of the *Rocket* was one hundred and thirty-eight square feet, that of the new locomotive 6,393 square feet. To heat this great surface oil is used for fuel, so that the task for the fireman is lighter than on many locomotives less than one-half the size.

On this locomotive there are two sets of cylinders driving two sets of driving-wheels on each side, making a total of sixteen drivers in all. From the size of these drivers it is evident that the engine is designed for strength rather than speed, although of course relatively high speed can be attained if desired. On the section of road over which it operates there is a maximum grade of one hundred and sixteen feet per mile, and it was for negotiating such grades with full loads that the locomotive was designed.

V

FROM CART TO AUTOMOBILE

The use of the wheel as a means of reducing friction dates from prehistoric times. The introduction of this device must have marked a veritable revolution in transportation, but unfortunately we have no means of knowing in what age or country the innovation was effected. We only know that the Chinese have used wheelbarrows and carts from time immemorial, and that sundry very ancient pictures and sculptures of the Egyptians and Babylonians prove that these peoples were entirely familiar with wheeled vehicles.

The earliest form of wheel was doubtless a solid disk, and such a wheel is still in use in many places in the East; but the wheels of the Assyrian chariot were spoked after the modern fashion, and provided with rims of metal. The introduction of the wagon-spring, however, was a comparatively modern innovation. The use of springs very considerably reduces the resistance, thus adding to the efficiency of wheeled vehicles; but the reduction is not very obvious unless the roads are tolerably good, nor is it probable that the ancient nations could readily have measured the effect even had the idea of springs suggested itself.

As regards good roads, these are, to be sure, no modern invention, since the Romans had car-

ried the art of road-building to a very high degree of perfection. The integrity of the Roman Empire depended very largely upon the highways that linked all parts of its circumference with the Imperial center; and in a perfectly literal sense all its roads led to Rome. The Roman road-bed was constructed of several layers of stone, and it was one of the most resistant and permanent structures ever devised. As late as the sixteenth century of our era there were no roads worthy of the name in England except the remains of those constructed many centuries before by the Roman occupants. It was not until well toward the close of the eighteenth century that Macadam and Telford devised methods of road-making whereby broken stone and gravel, pounded to form a smooth surface, gave the modern world road-beds that were in any way comparable to those early ones of the Romans.

This development of road-building corresponded, naturally enough, with an advance in the art of carriage-building, and the increased popularity of stage-coaches. We are told that about 1650 the average rate of speed of the stage-wagons in England was only four miles an hour; whereas the stage-coaches moved over the improved road-beds of the nineteenth century at an average speed of about eight miles an hour, which was sometimes increased to eleven miles. After about the year 1836, however, the stage-coach was rapidly displaced by the steam-railway, and the interest in road-beds somewhat abated until brought again prominently to public attention by the users of bicycles and automobiles.

THE DEVELOPMENT OF THE BICYCLE

It is rather surprizing to learn that in point of time the automobile antedates the bicycle. Yet such, as we shall see in a moment, is the fact. Every one is aware, however, that the bicycle came into popularity at a time when the very existence of the automobile had been practically forgotten, and that subsequently it lost its popularity almost over night when the automobile came to its own. Viewing the subject retrospectively, perhaps the most singular thing is that both vehicles were so long delayed in making their way to public favor. There were, however, sundry very practical obstacles placed in the way of the larger vehicle; and the bicycle was not at first a device calculated to prove attractive to the average wayfarer.

The very earliest bicycle appears to have been the so-called hobby-horse or dandy-horse introduced about the year 1818 by Baron von Drais in France. It was a primitive vehicle, the user of which half rode and half ran, propulsion being effected simply by thrusting the feet against the ground. In effect the rider of the hobby-horse ran with a stride greatly lengthened through the partial support afforded by the saddle, and with correspondingly increased speed. He could, of course, on occasion coast down hill or on a level surface, when considerable momentum had been acquired, and supports for his feet were provided to facilitate this end. At first the machine promised to become popular, but it was soon ridiculed out of court.

Something like twenty years later—that is to

say, about the year 1849—a treadle-bicycle was invented by Kirkpatrick MacMillan, an English blacksmith. The machine did not become popular, however, and it was not until simple cranks were fitted to the front wheel of the bicycle that this form of vehicle came into anything like general use. This very simple expedient was first suggested, seemingly, by Pierre Lallament, a Frenchman, in 1866. His machine came to be known in England as the bone-shaker, and doubtless it deserved its name, for as yet neither the wire suspension-wheel nor the rubber tire had been invented. Both these improvements were quickly introduced, however; the suspension-wheel by Mr. E. A. Cowper, in 1868. The first rubber tires, used about 1870, were solid, and it was not until 1888 that the Irishman, Mr. J. B. Dunlap, introduced the pneumatic tire. Meantime the geared bicycle, with which every one is nowadays familiar, had been introduced in 1879 by M. H. J. Lawson and brought to the familiar form of the "safety" in 1885 by Mr. Starley. The combination of low wheels geared to any desired speed with pneumatic tires was the finishing stroke.

The problem of making the bicycle a relatively speedy vehicle had indeed been solved by the use of a large wheel—sometimes sixty inches in diameter—operated by a simple crank after the manner of the early machine of Lallament; but while bicycles of this type attained a considerable measure of popularity, the danger of taking a "header" on encountering any obstacle in the road was one that seemed to the average person to outmeasure the pleasure or benefit

to be derived from rapid transit thus attained. The safety bicycle, however, practically eliminated this danger. It was, moreover, comparatively easy to balance; and not long after its introduction in perfected form, with pneumatic tires, it had made an appeal to which all the world responded. For a few years the safety bicycle was the most conspicuous of vehicles on every country road, and partizans of outdoor life believed that the health and stamina of the generation were to be increased immensely by the new vehicle.

Nor were these anticipations altogether visionary, as undoubtedly the bicycle did do much to improve the average health of nearly all classes of citizens. But its popularity was too suddenly acquired to be permanent, and at the very moment when it was most used another vehicle was suddenly developed which was to lead to its practical abandonment by the great mass of people for whom it might have been supposed to afford a means of permanent recreation.

THE COMING OF THE AUTOMOBILE

The vehicle that effected this sudden eclipse of the bicycle is, as every one knows, that form of power-driven carriage known in England as the motor-car, and in France and America as the automobile. The first form of this vehicle to gain popularity was a tricycle driven by a small steam-motor. But almost immediately the recently devised gas-engine was called into requisition, and after that the development of the automobile was only a matter of detail. But, as so often *happens* with practical inventions, there are dis-

puted questions of priority regarding the application of the gasoline-engine to this particular use. The engine itself was perfected, as we have elsewhere seen, about 1876, by the German, Dr. Otto.

It appears that in 1879 an American, Mr. George B. Selden, applied for a patent designed to cover the use of the internal combustion engine as a motor for road vehicles. Owing to technical complications the patent was not actually issued until the year 1895. Meantime, at least as early as 1885, Herr Daimler in Germany had used the gasoline-motor for the practical propulsion of a tricycle; and not long after that date the right to use his patents had been acquired in France by Messrs. Panhard and Levassor. These men soon applied the Daimler motor to four-wheeled vehicles of various types, and almost at a bound the automobile as we know it was developed. Early in the '90s the custom of having annual road races was introduced, and before the century had closed the automobile was everywhere a familiar object on the roads of Europe and America.

While the introduction of the automobile is thus a comparatively recent event, it should be known that the idea of using mechanical power to propel a road vehicle is by no means peculiar to our generation. Practical working automobiles were constructed long before any person now living was born. The very first person to construct such a vehicle was probably the Frenchman, Cugnot, who manufactured a steam-driven wagon, using the old Newcomen type of engine in the very year—by a curious coincidence—in

which James Watt took out his first patent for a perfected steam-engine; that is to say, in the the year 1769.

Cugnot's automobile was a heavy four-wheeled affair intended for military service. It actually progressed along the road at the rate of three or four miles an hour. But the problem of carrying fuel and water had not been solved, and either for that reason or because the authorities in charge lacked imagination and did not regard the device as offering advantages over traction by horses nothing came of Cugnot's effort except the scientific demonstration that the idea of a self-propelled vehicle was not merely the dream of a visionary. A second automobile truck of similar design made by Cugnot, a year or two later, may be seen to this day in the Museum of Arts and Measures in Paris.

A few years later—namely in 1785—an Englishman, William Murdoch by name, whose interest in steam-engines is evidenced by the fact that he was in the employ of Bolton and Watt, manufactured a small tricycle driven by a Watt engine. This vehicle, running under its own power, developed a good degree of speed; and had not Murdoch's employers forbidden him to continue his experiments, the practical automobile might perhaps have gained popularity an entire century earlier than it did.

As the case stands, however, the automobile of Murdoch failed as signally as had that of Cugnot to gain general recognition. But it is quite possible that a knowledge of the device had come to the attention of another Englishman, Richard Trevithick by name, who was at once a prac-

tical experimenter of great skill and a man of fertile imagination. Trevithick, himself the inventor of a high-pressure steam-engine, adjusted his engine to a large road vehicle, and in the year 1804 exhibited this automobile on the roads of Cornwall, and subsequently in London, where it would probably have made its way had not the inventor been an extremely erratic genius, who presently shut up his coach and turned his attention to another form of vehicle. This, it will be observed, was full twenty-five years before that memorable date on which Stephenson launched his famous *Rocket*. Nothing came of Trevithick's experiment at the moment, beyond the demonstration of a principle—which indeed was much; but it was not long before various other inventors took up the idea, and as early as 1824 a number of automobiles, some of them weighing as much as three or four tons, were in successful operation on the highways of England. Some of these even gave regular passenger service, and attained the unprecedented speed of twelve or fourteen miles an hour. All this, it will be observed, was before the first locomotive running on rails had attracted any attention. Stephenson had indeed begun his experiments, but up to this time they had been confined exclusively to tramways in connection with collieries.

In the year 1829 Stephenson made his famous demonstrations with the *Rocket*, a locomotive running on rails, which attained a speed of thirty miles an hour, contrary to all the predictions of the wiseacres, who had declared the inventor a lunatic for hoping to attain even ten miles.

We have already noted that the railway on which the test was made was not built with the expectation of utilizing steam-power, that being regarded as a dreamer's vision. Lord Darlington prevented the construction of the road for a time because it chanced to run near his fox covers; and the legislative permission was finally secured only with the proviso that the railway was to avoid the region of the preserves. Stephenson with difficulty secured permission to make an experiment on the railway with his engine, in competition with other would-be inventors; and it was his unexpected success that turned the scale in favor of steam-power. But even the startling success of the *Rocket* did not make a great impression upon the British public, the incident being given but slight notice in the periodicals of the day, and no mention being made of it in the *Annual Register*.

All this is of interest as showing the attitude of a conservative public toward the steam locomotive running on a railway, and as partially explaining the antagonism to self-propelled road vehicles which found, most unfortunately, an exponent in no less a personage than the Duke of Wellington, then prime minister. The opinion and attitude of the duke were made evident in 1829, in connection with a steam-automobile invented by a Mr. Gurney, which was capable of running on an ordinary road at a rate of at least ten miles an hour. The duke was old, and age had strengthened his inherent conservatism. He lent a ready ear to the claims—largely instigated, no doubt, by persons interested

in horse traffic—that the automobile on an ordinary road was a menace to public safety, and no doubt his influence had a large share in helping on the unfavorable public opinion and the adverse legislation which were presently to block the further progress of the motor-car.

Doubtless also the amazing success of the railway locomotive tended to attract the attention of the public away from the automobile, and thus made possible the passage of restrictive laws. In any event, the motor-car, notwithstanding its demonstrated possibilities, virtually passed from the scene at about the time when the railway locomotive made its spectacular entrance. That public interest in the matter did not subside immediately, however, is evidenced by the fact that such a book as Gordon's *Treatise on Elementary Locomotion by Means of Steam-Carriages on Common Roads* passed through three editions between the years 1832 and 1836.

AN EXTRAORDINARY PIECE OF LEGISLATION

Indeed, notwithstanding legislative rebuffs, here and there an inventor kept up his experiments, and in 1861 the automobile had attained so much prominence as to be given parliamentary attention. Four years later, in 1865, an extraordinary law was passed which deserves to be remembered as one of the greatest monuments of legislative folly ever recorded in connection with an economic question. This law provided that, in the case of any locomotive moving on a public highway, the number of persons required to drive the engine should be increased to three,

and that the vehicle should be preceded by a man with a red flag.

The latter provision suggests at first sight that the British legislator had here been moved to curiously un-British facetiousness; but there was really no such intent, as another provision of the law, limiting the maximum speed to four miles an hour, sufficiently testifies.

Other laws of similar tenor supported this one, and the validity of these decrees was finally sustained through an appeal to the Court of Queen's Bench, which brought forth the decision that the law applied to every type of self-propelled vehicle from the traction-engine to the Bateman steam-tricycle. Naturally, this decision gave the quietus to automobile—or, to use the more English word, motor-car—progress in Great Britain.

It appears, then, that the idea of an automobile traveling on an ordinary highway preceded that of the locomotive railway. It was, indeed, by far the more natural idea of the two, since tramways were at that time but little used outside of collieries. And it seems scarcely open to doubt that the repressive legislation was directly responsible for deflecting the progress of mechanical invention away from what seemed the more natural direction of development. It is always hazardous in such a case to attempt to guess what might-have-been under different circumstances; but considering the practical results already achieved as early as 1824, one can scarcely avoid the conviction that had legislation favored, instead of opposing, the inventor, the *automobile* might have been developed in Great

Britain as rapidly as railway traffic; in which event the middle of the nineteenth century would have seen the world at least as near the horseless age as we are in reality at the close of the first decade of the twentieth century. What this would have meant in its economic bearings on civilization during the past fifty years, the least imaginative reader can in some measure picture for himself.

In opposition to this view it might be urged that the real progress of the automobile has taken place since 1885, when the Daimler oil-engine was substituted for the steam-engine in connection with motor vehicles. But in reply to this it must be remembered that the workable gas-engine had been invented as early as 1860, and that the Otto engine, of which the Daimler is a modification, was patented as early as 1876. These developments, it will be noted, took place at just about the time when the new interest in the automobile had been aroused, as evidenced by the repressive British legislation just referred to. It can be but little in question that had the early interest in the British automobile been maintained, inventive genius would long since have provided a suitable motor. There was no incentive for the English inventor during those long years when the automobile was under legislative ban; and in the meantime the idea of the highway automobile seems not to have taken possession of other nations.

When that idea did make its way, it was very soon put into tangible operation, as everybody knows. And the fact that England made no

progress whatever in this line until the repressive laws were repealed in 1896, whereas France, Germany, and America had leapt far ahead in the meantime, is in itself demonstrative. Moreover, as regards the question of a motor for the automobile, it should not be forgotten that the steam-engine is by no means obsolete. The victories of Mr. Ross's machine at Ormonde in 1905, and of the Stanley steamer in 1906 (a mile in 28 1-5 seconds), show that steam is distinctly a factor, notwithstanding the popularity of the gasoline-engine. The steam-motor might have served an admirable purpose until such time as a better power had been developed.

No animal can for a moment compete with the automobile in speed. It might be supposed that the space-devourer would find a match in the flying bird. But it is not quite certain that the supposition is valid. The old-time books on natural history tell us, to be sure, of flight-speeds that make the new records seem slow. They credited the European swift, for example, with two hundred and fifty miles an hour. But more recent observers, made cautious by the scientific spirit of our age, are disposed to discredit such estimates, which confessedly are little better than guesses.

The only officially timed bird flights are the flights of homing pigeons; and here the record credits the homing bird with only one hundred miles an hour. This means 124 feet a second, as against the motor's 193. According to these figures, the automobile could give the pigeon a start of almost two thousand feet and yet sweep *forward* and overtake it in its flight, before it

passed the mile-post. Perhaps the comparison is not quite fair, since no doubt the pigeon may perform some individual miles of its journey at more than the average speed; but it may well be doubted whether its maximum ever reaches the mile-rate of 25.40 seconds.

It is within the possibilities, however, that some other birds have even surpassed this speed. The falcon, for example, is probably a swifter bird than the pigeon, at least for short distances. Some one indeed has credited the hawks with a speed of one hundred and fifty miles an hour. But this, I feel sure, is a great exaggeration. I once saw a hen-harrier pursue a prairie-chicken, without seeming to gain appreciably for a long-distance; yet the prairie-chicken is by no means among the speediest of birds. Many of our ducks, for example, quite outclass it; indeed, I should be disposed to admit that the teal or the canvasback at full speed might give the automobile a race.

There is, to be sure, one way in which the bird might get the better of a machine, thanks to its capacity to rise to a height. This would be by taking a sloping course downward. The little shore-lark often gives an exhibition of the possibilities open to the bird in this direction. After rising to a cloudlike height it soars about for a time singing, then suddenly sweeps downward, and, closing its wings, launches itself directly toward the earth, falling with meteoric speed till it almost reaches the surface, when it makes a parachute of its wings and swoops away in safety. During this performance the little lark is, I veritably believe, the swiftest

moving animate thing in all the world. But there is a reason why the bird could not increase its speed indefinitely by imitating the lark's feat in a modified form, and this is the obstacle of atmospheric pressure. Air moving at the rate of sixty feet a second constitutes a serious storm; at ninety feet it becomes a tornado, and at one hundred and fifty feet it is a tornado at its worst —a storm that tears up trees and overthrows houses, and against which no man can stand any more than that he could breast the current of Niagara. Now, of course, it is all one whether the air moves at this rate against you or whether you move at a corresponding rate against the air —action and reaction being equal. Therefore, a very serious check is put upon the bird's flight; and it is this consideration which makes it seem doubtful whether any bird, except when aided by a strong wind, can attain such speeds as have been suggested.

Of course, atmospheric pressure affects the automobile no less than the bird. In record-breaking speed tests of the automobile, machine and driver are in effect subjected to the influence of a veritable tornado. Theoretically it seems almost incredible that any power could drive a ton of metal against the air at such a speed; practically we see the feat accomplished. But the automobilist has tales to tell of the power of the wind against his face that are easily credible. Even at ordinary speed in a touring-car, as most of us can testify, the wind blows a gale, veritably forcing tears from the eyes of the novice and blowing them back over his ears. To modify the antagonism of the wind, the

constructors of racing motor-cars adopt a model suggested originally by the body of a bird or of a fish, and long since made familiar by the shipbuilder.

A MIRACULOUS TRANSFORMATION OF ENERGY

Most of the automobiles, as everybody is aware, are propelled by gasoline-engines. This is not their least wonderful feature. To the ordinary observer it seems quite incredible that a little whiff of air mixed with the fumes of a few drops of gasoline should produce a power that can drive pistons with such force as to throw forward what is virtually a bullet weighing more than a ton.

The power that propels this amazing projectile consisted in the aggregate of a few cubic feet of gaseous vapors. The forward motion of the piston sucked a whiff of the gasoline vapor and air into the cylinder; the backward motion of the piston comprest this gas; an electric spark ignited it; the heat of the electric spark enabled the gasoline molecules to unite with the oxygen molecules with explosive suddenness; the conflagration thus started spread instantly to other parts of the comprest gas; the myriad particles of the gas, rebounding from one another at inconceivable speed, prest with the aggregate power of multitudes upon the cylinder, and drove it back with terrific force; then an escape valve opened; the return thrust of the piston drove out the exploded gas, and one revolution of the engine was complete.

Over and over again this cycle was repeated;

each revolution requiring for its performance but a bare fraction of the time required to describe it. The thing is simple enough in practise, but it is a marvelous mechanism when you stop to think of it. That such power should be latent in a seemingly harmless whiff of gas is one of Nature's miracles. And that man should have constructed an engine so nicely adjusted in all its parts as to utilize this power is little less than a miracle of mechanics.

A word should be said about another interesting mechanism that pertains not indeed to the speed of the automobile, but to an accurate record of that speed. That is an electrical timing-device with which absolute accuracy of timing is assured. A moment's reflection will show that it would be quite impossible to time the automobile moving at record speed by the old stop-watch method. The nervous impulse through which the mandate of the brain is conveyed to the hand, and thus made to operate on the stop-watch, travels along the nerve of the arm at the time required for the brain itself to act on the message from the eye, is distinctly appreciable, and every one is aware that individuals differ as to their reaction time.

The practical result, therefore, is that timers are often at variance to the extent of as much as two-fifths of a second. Now in two-fifths of a second the record motor-car covers a distance of over eighty-two feet, as represented by Burman's mile made in 25.40 seconds. Obviously such latitude in measurement could not be permitted. Hence an electric device has been elaborated which tests the speed with absolute ac-

curacy, recording it automatically on a strip of tape. Therefore the fractional seconds are now stated in hundredths instead of in mere quarters or fifths, and we may be confident—as we could not always be regarding the old-time records—that the different fractions of a second represent an actual difference of speed.

It may be of interest to make a comparison between the speed of the record automobile and the fastest speed ever attained by a railway locomotive—namely, a mile in thirty seconds. The gap is by no means an insignificant one. A mile in thirty seconds means 176 feet a second. This would allow the champion automobile a lead of over twenty-nine feet each second; and at the end of a mile the locomotive would be distanced by over 716 feet. It is interesting to visualize the procession that the automobile would leave behind if placed in competition with the various kinds of champions whose feats have been mentioned. As the automobile crossed the line the locomotive would be one-sixth of a mile in the rear; 2,100 feet farther back would come the homing pigeon; after a long gap Salvator, the first runner, would come straggling along, having covered about one-fourth of a mile; Lou Dillon would be just reaching her first fifth of a mile; the fastest cyclist would be placed between the racer and the trotter; while the swiftest runner at the distance would have gone only about 200 yards from the tape.

VI

THE DEVELOPMENT OF ELECTRIC RAILWAYS

The United States has been preeminent in the development of street-railways of all kinds, from the earliest type of horse-car to the modern city and interurban electric cars. Nevertheless, very few of the great general underlying principles upon which these numerous inventions are based have been discovered upon this side of the Atlantic. American inventors have simply excelled in applying the known general principles to practical mechanisms. But altho the American inventors have largely monopolized this field of progress, the names of many Europeans also are connected with it. In several instances these foreign inventors, as naturalized American citizens, have done their work in America, being attracted to this country by the exceptional opportunities offered.

The invention of the commercial dynamo, shortly after the middle of the nineteenth century, opened the era of practical electric-railway construction on both sides of the Atlantic. The German experimenters, Siemens and Halske, and later the American, Stephen D. Field, paved the way by numerous experiments and discoveries. It was not until about 1880, however, that the idea of using a third rail for transmitting the current was conceived. Hitherto, most of the in-

ventors had attempted to use one rail as a receiving part of the circuit to the motor, the other rail completing the return part of the circuit. And it was several years after the idea of the third rail had germinated before the attempts to utilize one of the traction rails for conveying the current was abandoned.

THE EDISON ELECTRIC LOCOMOTIVE

In 1880, Mr. Thomas A. Edison, at Menlo Park, New Jersey, perfected a series of electric-railway motors and locomotives that were actually employed in hauling freight and passengers. The following year Mr. Edison made a contract with Mr. Henry Villard, which stipulated that the inventor was to construct an electric railway at least two miles and a half in length, which was to be equipped with two locomotives and three cars, one locomotive for freight and one for passengers, the passenger locomotive to have a capacity of sixty miles an hour. It was agreed that if the experiment with this railway proved successful Mr. Villard was to reimburse Mr. Edison for the actual outlay, and to install at least fifty miles of electric road in the wheat regions of the Northwest.

The electric locomotives built by Mr. Edison were constructed along the usual lines of steam locomotives, with cab, headlight, and cowcatcher, the motive power being applied from the motors to the axle by means of friction pulleys. This method was soon abandoned, as the pulleys slipt a great deal before the locomotive actually started. A system of belts which was substitute

proved more satisfactory. The current was conveyed to the motor through the track, and was supplied to the road by underground cables connecting from the dynamo-room of Mr. Edison's laboratory. The rails were insulated from the ties by coatings of Japan varnish, and by placing them on pads made of muslin impregnated with tar.

From the very first this road gave promise of success. The tireless genius of Edison was constantly finding and correcting defects, and there was every prospect that in a few months a practical and economical electric railway would be an accomplished fact. Then came the financial crash of the Northern Pacific Railway, involving the fortune of Mr. Villard, and tying the hands of the inventor at Menlo Park for the time being.

The year following, however, Mr. Field and Mr. Edison combined their forces and formed a company for perfecting and constructing electric locomotives and railways. In the same year an electric railway was put in operation at the Chicago Railway Exposition, the chief promoters of this enterprise being Messrs. Field, F. B. Rae, and C. O. Mailloux. In the gallery of the building a circular track, something like a third of a mile in length, was laid, and on this an electric locomotive named *The Judge* hauled a single car which carried over twenty-six thousand passengers in the month of June. In the Autumn of the same year, *The Judge* was used for hauling passengers on a track at the Louisville Exposition. It was capable of attaining a speed of twelve miles an hour, and its average speed was

eight miles. It was twelve feet long over all, weighed something like three tons, and, like Edison's locomotive, was equipped with cow-catcher, headlight, and cab. The current was taken from a surface, or feed rail, by means of bundles of phosphor-bronze wire, so arranged that a good clean contact would be made on each side of the rail whether the car was moving forward or backward.

THIRD RAILS AND TROLLEYS

At the same time an Englishman named Leo Daft, then living in America, was making some important experiments with motors for the purpose of driving machinery, these motors being operated from central power-stations located at distant points. Mr. Daft constructed an electric locomotive, and in November, 1883, constructed what was known as the Saratoga and Mount MacGregor Railroad. This railroad was twelve miles in length and included many steep grades. The locomotive, which hauled a regular passenger-car, received the current from a central rail. The year following Mr. Daft built and equipped a small road on one of the long piers of Coney Island, which carried something like forty thousand passengers in one season. It was an improvement over the Siemens electric railway established in Germany in 1881—which, however, was the first road ever established.

The following year the inventor began the equipment of the Baltimore Union Passenger Railway Company, a line that ran a distance of about two miles and reached an elevation of

hundred and fifty feet above the city of Baltimore. This road was put into regular operation in 1886, and was the second electric street-railway in America for carrying on regular passenger service.

The Baltimore Union Railway had several novel and important features, one of them being the equipment of part of the line with an overhead-trolley service, the practical importance of which had been demonstrated shortly before by Van Depoele. The projector, Mr. Daft, also built several other lines in different parts of the country, constantly improving upon his earlier efforts, sometimes using two overhead trolley-wires, with two trolley contacts, thus doing away with the use of the track as a means of current supply, or for use as part of the circuit. Altho in recent years double overhead trolleys have largely disappeared, some of them are still in use both in America and in Europe.

Van Depoele was a Belgian who had come to America in 1869. Altho primarily a cabinet-maker, he had a great liking for the study of electricity, and devoted all his spare time and money to efforts to solve the problem of practical street-car propulsion. In 1883, at the Industrial Exposition at Chicago, he operated a car by electricity, using an overhead-trolley system somewhat similar to Daft's. By 1885 he had made sufficient progress to construct a line one mile long for carrying passengers from the railway station to the Annual Exhibition grounds at Toronto, Canada. On a single track he operated three cars and a motor, carrying an average of ten thousand passengers daily, his

train sometimes attaining a speed of thirty miles an hour. For receiving the current he used an underrunning trolley and pole very similar to the form now in common use, this being one of the first instances of employing this particular method of receiving the current. In this system an insulated track was used for returning the current.

Van Depoele's next venture was the equipment of an electric railway at South Bend, Indiana, on which five separate cars were operated at one time—a thing supposed by many to be impossible. The cars of this road were equipped with motors placed under the cars instead of above them, thus saving valuable seating-space. In place of the underrunning trolley and pole, however, the current was taken from the overhead wire by means of a flexible cable. Later Van Depoele invented an underrunning trolley and pole, taking out the original patents. His claims to priority were contested eventually, but they were sustained by the United States courts.

At this time there were at least a score of inventors whose work added something of importance to the solution of the problem of electric traction. But without belittling others, it is probably only justice to say that the work of Frank J. Sprague, a one-time lieutenant in the United States Navy, marks the beginning of the modern era of street-railways. In 1888, after a period of struggle and a series of disheartening disasters, Mr. Sprague and his associates opened an electric line for the Union Passenger Railway of Richmond, Va., which "forms

a landmark in the history of this industrial development." Over a line of road with grades at that time considered impossible, thirty cars were put into use at the same time, the contract for the equipment calling for its completion in ninety days. The success of this enterprise, when on the opening day more electric cars were operated than in all the rest of America together, settled forever the question of the practicality of electric street-railways, as well as many of the questions of the practical application of the current, thanks to Sprague's inventive genius.

This road was an overhead trolley-wire system, with an underrunning trolley held in place by the now familiar trolley-pole. The number of difficulties that had to be solved in perfecting this apparently simple piece of apparatus is shown by the statement of Mr. Sprague that "probably not less than fifty modifications of trolley-wheels and poles were used before what is known as the 'universal movement' type was adopted."

In this connection the origin of the word "trolley" is interesting. It seems to have been corrupted from the word "troller" by the workmen of a Kansas City car-line. On this line an overhead wire was used, the traveling carriage taking the current from the wire being known as the "troller." The employees of the road, however, shortly corrupted "troller" into "trolley"; and "trolley" it has remained ever since.

As in the case of Van Depoele, whose perfection of the underrunning trolley was contested *legally*, Sprague's great contribution to electric

traction, the suspension of the motor directly upon the axle, had finally to be sustained by the United States courts. Sprague's method was to hang the motor under the car directly upon the axle, by an extension or solid bearing attached directly to the motor. This plan of constructing the motor, together with numerous other improvements, principally in the direction of lightness, simplicity, and adaptability, soon superseded all preexisting methods of construction. Thus Van Depoele's method of taking the current from the wire, and Sprague's method of utilizing it in the propulsion of the car, must be regarded as epoch-marking steps in the history of electric traction. Sprague's invention demonstrated the validity of his contention, now universally accepted, that motors should be placed under each car instead of being used on locomotives.

STORAGE-BATTERY SYSTEMS

From the earliest attempts at solving the question of electric traction, efforts were made to produce some form of storage-battery whereby the cars might be made independent of a distant generating plant. The advantages of a self-contained vehicle are so obvious that it is not surprizing to find the inventors persistent in their attempts at producing practical cars of this type. Such battery cars would not require the dangerous, expensive and cumbrous system of overhead wires, or the more sightly but also more expensive system of conduits. With such a system of cars the elaborate mains and feed-

ers for bringing the current to the track from the power-house, and for effecting the return circuit, could be dispensed with. Moreover, the independent action of such cars over a system where the power is furnished from a single source, where the stoppage of the current stops every car along the line, is inestimable.

Between the years 1880 and 1883 many storage-battery cars were built and put in service both in European and American cities. Probably the most important one of these lines was that which was built by the Belgian, Mr. E. Julien, in New York City, in 1887-8. On the Fourth Avenue road something like a dozen storage-battery cars were put in operation for a considerable time, and later improved modifications of these cars were operated in Philadelphia under the direction of Mr. Anthony Rackenzaun, of Vienna. But, despite the apparent simplicity of the storage-battery idea, innumerable difficulties were perpetually presenting themselves in its practical application. Despite the disheartening results, however, storage-battery cars were not entirely abandoned in practise until 1903, New York City being the last to surrender, as it had been about the last to adopt them.

But in February, 1910, the storage-battery street-car again made its appearance on trial in New York—not the old heavy type of unsatisfactory car, but an entirely new and lighter creation of Thomas A. Edison, who had been striving for years to solve the storage-battery problem. This car, which had been tested on the Orange, New Jersey, street-car line on January *20, 1910,* maintained a speed of fifteen miles

an hour in actual practise, and ran a distance of about one hundred and fifty miles without recharging the batteries.

There are some novel features about the car itself, but the all-important one is the peculiar and novel storage-battery which it has taken Mr. Edison some nine years to perfect. In an imperfect form this battery was given a trial in 1903, and much was expected of it because it was not only lighter than the usual form of storage-battery, but it promised more permanency because an alkali was used in place of an acid as an electrolyte.

In this battery the positive element, which consisted of nickel oxide interspersed with layers of graphite, was packed in perforated nickel tubes. The negative element was iron oxide, with potassium hydrate as the electrolyte. This battery showed no bad effects from overcharging or from being rapidly discharged, but it was found that the graphite soon became oxidized and interfered with the working of the battery. This defect was corrected by substituting chemically pure nickel for the graphite, but another was soon discovered. Under the pressure of the oxide of nickel the square tubes containing the nickel were frequently injured so that the powdered nickel oxide was sifted down on the pure nickel layers and insulated them.

The only solution of this difficulty seemed to be to pack the nickel in strong round tubes four inches long and about the size of a lead-pencil, the sides of the tubes being finely perforated. But the expense of producing such tubes by ordinary methods was prohibitive. A machine was

finally invented, however, which made the tubes economically by using spirally-wound ribbons of metal, the edges being fastened together during the coiling process. By the use of these tubes the battery was so far perfected that it was given extensive trials in 1908 on electric vehicles; and as these tests proved satisfactory, Mr. Edison began the construction of a specially designed street-car equipped with two 5-horse-power 110-volt motors of very light construction. The car weighs complete about five tons, and the batteries are stored under the seats running along each side.

This car was tested continuously for three weeks on one of the New York cross-town lines and performed its work so satisfactorily and economically that the management of the line decided to give the system a permanent trial. The regular daily run of this car averaged something over sixty-six miles, but this by no means exhausted the capacity of the batteries; and it is estimated that it could easily have run at least one-quarter farther without recharging. The surprizing feature of these tests was the low cost of running. The total cost of electric power for the day's run was about thirty cents, or 4.3 mills for each mile. The ordinary New York street-car costs on an average about five cents per mile for electrical energy; but, on the other hand, the carrying capacity of these cars is almost twice that of the Edison car.

The actual cost of running the car, however, was only one of its many advantages. The fact that no underground conduits have to be laid or overhead wires erected and maintained makes

the initial cost of installing the line far less than by any other system. The reduction in the cost of maintenance of the line is also an important item, as it is estimated that the cost of repairs on conduit lines is about $15,000 annually per mile.

MONORAIL SYSTEMS

The introduction of electricity facilitated the construction of monorail systems of roads, which had long been the dream of railroad constructors, since this power could be applied with so much more flexibility. The defects of the parallel rail system are apparent both in construction of the road-bed and the operating of trains. It is almost impossible to lay and maintain the rails in exact parallels, and even more difficult to keep each rail at the proper height at all points. Both these factors enter very largely into the determination of the speed that a train can make over such tracks, any very great variation from the parallel causing derailment, while slight depressions or elevations of either rail cause violent and dangerous rocking of the cars traveling at high speed.

In any monorail system the first of these difficulties, the deviation of the rail from the parallel, is, of course, eliminated; and it is found that on a single rail the elevations and depressions are not serious obstacles. Moreover, the cost of construction of a single-rail track must obviously be less than for a double-rail track, and the power necessary to operate cars over such a track far less. But until the invention of the gyrocar (which is referred to at length in the

following chapter) the methods of balancing the car on a single rail presented difficulties which quite offset the advantages of the monorail system. Some of these methods are unique and a few of them are practical in actual operation.

In Germany a suspension monorail system is in operation, the cars being suspended from an overhead track. But obviously such a system, which requires elaborate and expensive steel trestle-work along every fork of the road, is not adapted to the use of long-distance roads except in thickly populated districts. A less expensive and highly satisfactory system is the one invented by Mr. Howard Hansel Tunis and used at the Jamestown Exhibition in 1907.

In this system the wheels, arranged in tandem, have double flanges which keep them on the single-rail track, and the cars are prevented from toppling over by overhead guides. These guides must be supported on a framework, but as there is little tendency to sway on a single-rail track, they can be relatively light structures. It is the cost of these frames, however, that practically offsets the low cost of road-bed construction, so that, everything considered, the mere matter of initial cost has no very great advantage over the ordinary double-rail road. But the cost of operating is considerably less than the older type, and this road would undoubtedly come rapidly into popularity but for the fact that such gyro-cars as the ones invented in England and Germany are self-sustaining on the rail, doing away with the expensive overhead framework construction, and are likely to become practical factors in the problem of transportation.

In 1909 an electric aerial monorail up the Wetterhorn in the Alps was put into operation. On this line a car suspended on two cables, one above the other and without supports except at the upper and lower terminals, rises at an angle of forty-five degrees through a distance of 1,250 feet. There are two sets of these cables, each carrying a car so arranged as to work in alternate directions simultaneously, this counterbalancing effecting a great saving in power. The power-plant is located at the upper end of the ascent, and consists of winding drums actuated by electricity which raise and lower the cars by means of cables. On the cars themselves, therefore, there is no power, but each car is equipped with brakes powerful enough to stop and hold it notwithstanding the steepness of the incline.

There is nothing particularly novel in the principles involved in this aerial road, but it is the first of its kind to be built for passenger traffic. Similar less pretentious roads have been in use for freight transportation for several years. But the success of this road means the building of others on inaccessible mountain inclines where the laying of ordinary road-beds is out of the question, and the operating of cog-roads too expensive.

VII

THE GYROCAR

On the 8th of May, 1907, Mr. Louis Brennan exhibited, at a *soirée* of the Royal Society in London, a remarkable piece of mechanism, which stirred the imagination of every beholder, and—next morning—as reported by the newspapers, aroused the amazed interest of the world. This invention consists of a car run on a single rail, standing erect like a bicycle when in motion; but, unlike the bicycle, being equally stable when at rest.

It is a car that could cross the gorge of Niagara on a tight rope, like Blondin himself, but with far greater security; a car that shows many strange properties, seeming to defy not gravitation alone but the simplest laws of motion. For example, if a weight is placed on one edge of the car that side rises higher instead of being lowered.

If you push against the side with your hand, the mysterious creature—you feel that it must be endowed with life—is actually felt to push back as if resenting the affront.

Similarly, if the wind blows against the car, it veers over toward the wind. If the track on which it runs—consisting of an ordinary gas-pipe or of a cable of wire—is curved, even very sharply, the car follows the curve without difficulty,

and, in defiance of ordinary laws of motion, actually leans inward as a bicycle rider leans under the same circumstances, instead of being careened outward as one might expect.

A curious mechanism, surely, this new car, with its four wheels set in line, bicycle-fashion, running thus steadily. But strangest of all it seemed when it poised and stood perfectly still on its tight-rope, as no Blondin could ever do. As stably poised it stood there as if it had two rails beneath it instead of a single wire; and there was nothing about it to suggest an explanation of the miracle, except that there came from within the car the murmur of whirling wheels.

The mysterious wheels in question would be found, if we could look within the structure of the car, to be two in number, arranged quite close together on each side of the center of the car. They are two small fly-wheels, in closed cases, revolving in opposite directions, each propelled by an electric motor. These are the wonder-workers. They constitute the two-lobed brain, or, if you prefer, the double-chambered heart of the strange organism. All the world has learned to call them gyroscopes. The vehicle that they balance may conveniently be termed a gyrocar —a name that has the sanction of the inventor himself.

Let it be understood once for all that a gyroscope is merely a body whirling about an axis. A top such as every child plays with is a gyroscope; a hoop such as every child rolls is a gyroscope; the wheels of bicycles, carriages, or railway-cars are gyroscopes; and the earth

itself, whirling about its axis, is a gyroscope. You can make a gyroscope of your own body if you choose to whirl about, like a ballet-dancer. In a word, the gyroscope is the most common thing imaginable. Indeed, if I wished to startle the reader with a seeming paradox, I might say without transcending the bounds of truth that, in the last analysis, there is probably nothing known to us in the universe but an infinitude of gyroscopes—atoms and molecules at one end of the scale; planets and suns at the other—all are whirling bodies. Still there are gyroscopes and gyroscopes, as we shall see.

GYROSCOPIC ACTION EXPLAINED

Now a word about gyroscopic action. If you have rolled a hoop or spun a top you have unwittingly learned some practical lessons on the subject which, had you possest Mr. Brennan's imagination and ingenuity, might have enabled you to anticipate him in the invention of the gyrocar. Harking back to the days when you rolled hoops, you will recall that the child who most excelled in the art was the one that could make the hoop go fastest. The hoop itself might be merely a wheel of wire, which would fall over instantly if not in motion; but if given a push it assumed an upright position and maintained it with security, so long as it was impelled forward. It seemed able, so long as it whirled about, to defy the ordinary laws of gravity. A bicycle in motion gives an even more striking illustration of the same phenomenon. And best of all, a spinning-top. Every one knows how

this familiar toy, which topples over instantly when at rest and can in no wise be balanced on its point, rises up triumphant when whirled about, and stands erect, poised in a way that would seem simply miraculous to all of us, had we not all spun tops at an age when the world was so full of wonders that we failed to marvel at any of them.

All these familiar things illustrate one of the principles of gyroscopic action which Mr. Brennan has put to account in developing his wonderful car—the fact, namely, that every revolving body tends to maintain its chief axis in a fixt direction, and resents—if I may be permitted to use this expressive word—having that direction changed. The same principle is illustrated on a stupendous scale by our revolving earth, which maintains the same tilt year after year as it whirls on its great journey, notwithstanding the fact that the sun and the moon are tugging constantly at its protuberant equatorial region in a way that would quickly change its direction if it were not spinning.

But note, please, that whereas the whirling body assumes a certain rigidity in space as regards the direction in which its axle points, the mere translation of the body itself through space in any direction is not interfered with in the least, provided the axle is kept parallel with its original position.

You may test this if you like in a very simple way. Remove one of the wheels of your bicycle, and carry it about the room, holding it by the axle while it is spinning rapidly. You will discover that it requires no more force to carry it when spinning than when at rest, provided you

do not attempt to tip it from its plane of rotation, but that if you do attempt so to tip it, the wheel seems positively to resist, exerting a force of which it did not show a trace when at rest. A large top, arranged within the kind of frames or hoops called gimbals, if you can secure such a one, will show you the same phenomenon; it will resist having its axis diverted from the direction it chanced to have when it was set spinning.

If you ask why the spinning wheel exerts this power, it may not be easy to give an answer. The simplest things are hardest to explain. No man knows why and how gravitation acts; no one knows why a body at rest tends always to remain at rest until some force is applied to it; nor why when a body is once in motion it tends always to move on at the same rate of speed until some counterforce stops it. Such are the observed facts; they are facts that underlie all the principles of mechanics; but they are matters of observation, not of explanation or argument. And the fact that a revolving body tends to maintain its axis in a fixt position is a fact of the same category.

So far as we can explain it at all, we may, perhaps, say that the inertia which the matter composing the wheel shares with all other matter is accentuated by the fact that its whirling particles all tend at successive instants to fly in different directions under stress of centrifugal force. At any given instant each individual particle tending to fly off in a particular direction may be likened to a man pulling at a rope in that direction.

If you imagine an indefinite number of men circled about a pole to which ropes are attached, and evenly distributed, each one pulling with equal force, it will be clear that the joint effort of the multitude would result in fixing the pole rigidly at the center. The harder the multitude pulled, so long as they remained evenly distributed about the circle, the more rigid the pole would become. But if, on the other hand, all the men were to stop pulling and slacken the ropes, the pole would at once fall over. The pole, under such circumstances, would represent the axis of the revolving wheel, which acquired increased stability in exact proportion to the increased velocity of its revolutions, and therefore of the increased force with which its particles tend to fly off into space.

But be the explanation what it may, the fact that the axis of a revolving wheel acquires stability and tends to maintain its fixt position in space is indisputable; and it is this fact which determines primarily the action of the little revolving wheels of the gyroscopes that balance Mr. Brennan's car. There are certain very important additional principles involved that I shall refer to in a moment, but first let us glance at the car itself and see how the gyroscopes are arranged. We shall find them fastened within the framework of the car, at its longitudinal center, in such a way that their axles are parallel to the axles of the ordinary car-wheels when the car stands in a normal position. Granted that the gyroscopes are thus transverse and normally horizontal, and at right angles to the track, the exact location of the mechanism within the car

is immaterial. But the two gyroscopes must revolve in opposite directions for a reason to be given presently.

MR. BRENNAN'S MODEL CAR.

The Brennan car as at first exhibited was only a working-model about six feet in length, and the gyroscopes that balanced it were about five inches in diameter. It seems almost incredible that wheels so small should be able to balance a car six feet in length, but it must be understood that these small gyroscopes whirl at the rate of about seven thousand revolutions per minute, and, of course, the gyroscopic force is proportionate to the rate of revolution. If we recall that a light hoop making perhaps fifty or a hundred revolutions per minute acquires a considerable stability, we shall cease to wonder at the rigidity of the axles of the wheels revolving at such enormous speed.

The model car accomplished the feat of carrying a passenger weighing about one hundred and forty pounds across a little valley on a wire cable, a voyage in some respects the most remarkable that any man has thus far been privileged to make. The car has shown that it can go up or down a sharp incline; but this, as a moment's reflection will show, does not involve any change of direction of the gyroscopic axle, and therefore involves only the ordinary laws of mechanics. It is all one to the gyroscope whether the car moves on the level or up or down hill, so long as it moves straight ahead.

Nor do the gyroscopes interfere in the least

with the turning of the car in passing round a curve, when the two of them are linked together, as Mr. Brennan links them, so that any lateral change in the axis of one is balanced by an opposite change of the axis of the other. With the single gyroscope, such as Mr. Brennan used when he first began his experiments, the car encounters difficulties at curves in the track.

But before we can understand how the two gyroscopes balance each other in such a way as to make the Brennan car lean in while passing about a curve, we must investigate more fully the action of the individual gyroscopes. I have already said that there is another principle involved as supplementary to the principle of the fixt axis; this we must now investigate.

Perhaps it would be fairer to say that what we have to consider is not a new principle but a complication as to the application of the principle of gyroscopic action already put forward. In any event there is an elementary fact about the gyroscope that I have not yet stated. It is this: In order that the gyroscope may exercise its fundamental property of holding its axis fixt, it must have that axis so adjusted that it is free to oscillate or wabble. That sounds distinctly paradoxical, but it is a very essential fact. If Mr. Brennan had merely fixt two wheels rigidly in the frame of his car, they would have had no appreciable effect in balancing it. Had nothing more than that been necessary, some one would have invented a gyrocar long ago. But very much more than that was necessary, as we shall see.

The complication of which I am speaking is

illustrated by the action of the simplest top, which likewise owes its stability to its wabble. Your top does not rise merely because it spins, but because it wabbles as it spins—wabbling being the familiar word for what the machinist calls "precession." A freely spinning top, if in equilibrium, has no inherency to rise up against gravitation, as your top may have led you to suppose. Your top rises because it is not spinning freely in equilibrium, its action being interfered with by the friction of the point on which it rests; it is seeking a position of equilibrium, which, owing to the location of its center of gravity, will be found when its spindle is erect. But a top supported at both ends and properly balanced does not tend to rise but only to maintain its position.

HOW THE BRENNAN GYROSCOPES WORK

It is such a balanced top as this that we must call to our aid in explaining the action of Mr. Brennan's gyroscopes. The explanation will involve the use of a diagram perhaps rather unpleasantly suggestive of the days when you studied geometry, and I fear I cannot hope to make interesting reading of the explanation. But it will be worth your while to follow it, that you may understand the action of one of the most remarkable and ingenious of inventions. Figure 1 represents a kind of top called a Foucault gyrostat. It is merely a top or gyroscope in gimbal frames, such as I have already referred to. With certain slight modifications, the diagram that represents it might also be a diagram of one

of the gyroscopes in Mr. Brennan's car. Indeed, it was such a top as this that led Mr. Brennan to his discovery. Once, while on a visit to Cannes, he purchased a top like this of a street vender—and the gyrocar is the outcome of the

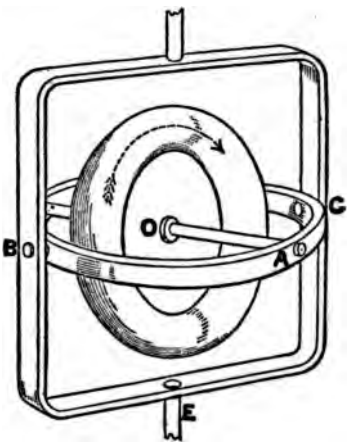

FIG. 1

studies he made with it. This is also the kind of top with which Foucault, after whom it is named, proved that the earth revolves; but we shall come to that story in another connection.

Reverting to the diagram, the gyroscope or top proper is at the center, revolving on the axis *O A*. It is pivoted on the frame *B A C*, which frame is in turn pivoted so that it can rotate on the axis *B C*. Lastly, the outer frame *B D C E*

is pivoted on the axis *D E*. Thus the apparatus as a whole is capable of revolving on each of its three principal axes. But under ordinary conditions it is only the inner wheel that is spinning. As this wheel is perfectly balanced, it will maintain steadily any position that it chances to have when it is set spinning, and the outer frames will remain stationary unless a disturbing force is applied to them.

Suppose, now, that the wheel has been set spinning on its axis *O A* in the direction indicated in the diagram. The wheel will then tend to maintain its position and resist any attempt to displace it. But its resistance will be shown in a very peculiar way—whereby hangs our tale. If you apply a steady downward pressure to the frame *B A C* at point *A*, attempting thus to deflect the axis of the spinning wheel of the gyroscope, the frame will not tip down as you expect it to do (and as it would do if the top were not spinning), but instead, it will move in a horizontal plane along the arc *C A B*, the entire mechanism rotating on the axis *D E*. This motion is equivalent to the wabble of the top, and it is called "precession."

Please remember the word and its meaning, for we must use it repeatedly.

But now, curiously enough, if you were to apply a sidewise pressure at *A*, pushing to the left (as we view the diagram) to help on the motion of precession, the obstinate apparatus will cease altogether to move in that direction and the point *A* will begin to rise instead, the frame *B A C* rotating on its axis *B C*. This rise of the axis *O A* will take place even tho the down-

ward pressure is continued. You have disturbed the equilibrium of the top—unbalanced it—and it must seek a new position. Contrariwise, if you would have the point *A* moved to the right, you must push it upward; if you would have it go down, you must push it to the right.

This seems rather weird behavior, but if you will note the direction of the arrow on the wheel you will see a certain method in it. It will appear that in each case the force you apply has been carried around a corner, as it were, by the whirling disk, and made to act at right angles to the direction of its application. This change of direction of a force applied is strictly comparable to the change effected by the familiar device known as a pulley. With that device, to be sure, a pull instead of a push is used, but this is a distinction without a difference, for pushing and pulling are only opposite views of the same thing.

Possibly this suggested explanation of the action of the gyrostat may not seem very satisfactory, but the facts are perfectly clear, and if you will bear them steadily in mind you will readily be able to understand the Brennan gyroscope, as you otherwise can not possibly hope to do. You have only to recall that pushing down at *A* causes motion (called "precession") to the left, and pushing up at *A*, motion to the right; and that in order to make *A* either rise or fall, you must "accelerate precession" by pushing to the left or to the right, respectively. But you must understand further, that when, through the application of any of these disturbing forces, you have forced the axis *O A* into

a new position, it will tend to maintain that new position, having no propensity whatever to return to its original position. It is quite as stably in equilibrium with its axis pointing upward as when in the position shown in the diagram. One position is quite like another to it; but having accepted a position it resents any change whatsoever.

Now we are prepared to understand the Brennan gyroscope, which consists essentially of two such gyrostats as that shown in our diagram A, set into the frame of the car on the axis *D E*, their wheels revolving in opposite directions and their outer frames so linked together that when one turns in one direction on its axis *D E*, the other must turn in the opposite direction. As the sole object of having two of the gyroscopes is to facilitate the going around curves, we may for the moment neglect the second one, and consider the action of only one of the pair.

Our diagram 2, then, will represent one of Mr. Brennan's gyroscopes in action. It is pivoted into the framework of the car on the axis *D E*. If you examine it you will see that it is essentially the Foucault gyrostat of our other diagram, with the axis *O A* projected beyond the frame to the point *F*.

In practise, the frame *B A C* is made to carry the field-magnet of an electric motor for spinning the wheel. But this in no wise affects the principles of action. Mr. Brennan's invention consists of the exceedingly ingenious way in which he applies these principles; and to understand this we must follow our diagram closely. Looking at it, you will see that the spindle *O F*

carries two rollers R_1 and R_2 which may come in contact under certain circumstances with the curved segments marked G_1, G_2, G_3, G_4, which are strong segments of car-frame itself—the segments, indeed, upon which the force of the gyroscope is expended in holding the car in equilibrium. It

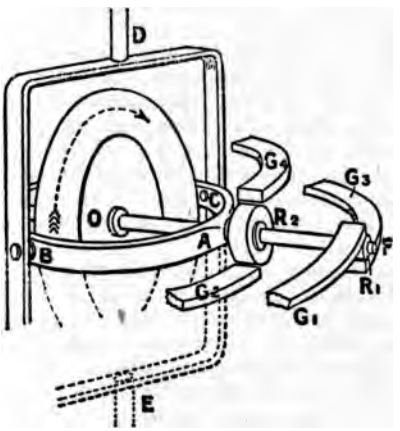

FIG. 2

must be understood further that the roller R_1, is loosely fitted to the spindle O F and hence can whirl with it when prest against the segment G_1 or G_3; whereas the roller R_2 is fitted about a non-revolving extension of the frame B A C, and not to the spindle itself. Bearing in mind that the gyroscope itself is perfectly balanced and hence tends to maintain its axis O F in a fixt direction, we shall be able to understand what

must happen when the car is tipped from any cause whatever—as the shifting of its load, the pressure of the wind, or the centrifugal action due to rounding a curve.

Suppose, for example, that the car tips to the right. This will bring the segment G_1 in contact with the roller R_1, and the roller will instantly tend to run along it, as a car-wheel runs along the track, because friction with the spindle causes it to revolve. But this, it will be evident, is equivalent to pushing the spindle F (or the frame A) toward B—"accelerating the precession"—and we know that the effect of such a push will be to cause the spindle (thanks to that round-the-corner action) to rise, thus pushing up the segment G_1, and with it the car itself.

The thrust will cause the car to topple to the left and this will free the roller R_4, but a moment later it will bring the segment G_2 in contact with roller R_2 which thus receives an upward thrust. But an upward thrust, we recall, will not cause the spindle to move upward, but off to the right toward C; and so a moment later still the roller R_2 will pass beyond the end of the segment G_2, and the roller R_1 will come in contact with the segment G_3, along which it will tend to roll, thus accelerating the precession to the right, and so causing the spindle to push downward, bringing the car back to its old position or beyond it; whereupon the segment G_4 will be brought in contact with R_3, retarding the further oscillation of the car and causing the spindle to move back again to the left.

This sequence of oscillations will be repeated

over and over so long as any disturbing force tends to throw the car out of equilibrium. In other words, the gyroscope, when its balance is disturbed by a thrust due to any unbalancing of the car, will begin to wabble and continue to wabble until it finds a position where it is no longer disturbed, and this new position will be attained only when the car as a whole is perfectly balanced again.

In this new position of balance, the car (owing to a shift of its load or to the force of the wind) may be tipped far over to one side, as a man leans in carrying a weight on one shoulder, to get the center of gravity over the rail, and in that event the axis of the gyroscope will be no longer horizontal. But that is quite immaterial. There is no more merit in the horizontal position than in any other, as regards the tendency to keep a fixt axis. If it is usually horizontal, this is only because under normal conditions the car will be balanced at its physical center, just as ordinarily a man stands erect and does not lean to one side in walking.

Reverting for a moment to our diagram and the explanation just given, it will be understood that the two rollers R_1 and R_2 are never in action at the same time, and that it is only the roller R_1 that gives the sidewise push that accelerates the precession (since R_2 is not in contact with the axle itself).

The function of R_2 is to retard the precession and bring the axis to its normal position at right angles to the rail on which the car runs. There is nothing of mystery about the action of either which the action of our gyrostat does

not explain, but the mechanism by which the different segments of the car are made to push against the spindle, and so force it to balance the car in order that it may maintain its own balance, is exceedingly ingenious. Mr. Brennan himself tells me that he has improved methods of accomplishing these results, which are not yet to be made public. The principle, however, is the same as that outlined in the earlier patents which I have just described.

If you have taken the trouble to follow carefully the description just given, you will be prepared to understand the anomalies of action of the gyrocar; for example, why its side rises when a weight is placed on it; why it leans toward the wind, and why it leans to the inner and not to the outer side of the track in rounding a curve. The substance of the explanation is that the greater the force brought to bear on the roller R_1 by the segment of the car that strikes against it, the stronger its precession, and hence the more powerful its lift. The oscillations and counter-oscillations thus brought about continue to operate powerfully on the roller R_1 so long as the weight of the car is out of balance; and balance is restored only when the heavier side of the car rises, bringing the center of gravity over the track, just as a man carrying a weight on the right shoulder leans toward the left, and vice-versa. Thus, when the gyrocar has a heavy weight on one side, or encounters a strong wind, it may lean far over, but still be perfectly and securely balanced, the gyroscopes finally remaining quiescent in their new position until some new disturbance is applied.

It remains to be said, however, that there is another element introduced when the car rounds a curve. To understand this, we must revert to the action of the Foucault gyrostat, as illustrated in diagram 1. If you held such a gyrostat in your hand in the upright position in which it is shown in the diagram, and whirled it about, the axis *O A* would of course maintain a fixt direction so long as the gyrostat was free to revolve on the axis *D E*. But if you prevented such revolution, as by clutching the spindle *E* firmly, and then whirled the gyrostat about at arm's length, the axis *O A* would at once be forced to take an upright position. If your hand whirled to the right, the point *A* would rise; if your hand whirled to the left, the point *A* would go down; the principle determining this motion in either case being that the direction of whirl of the gyroscope must correspond to the direction of curve given to the apparatus as a whole by the motion of your arm.

Exactly the same principle applies to the Brennan gyroscope when the car to which it is attached goes about a curve. The frame pivoted at *D E* revolves only within a limited arc, and then becomes fixt, and so the axis *O F* tends to tip upward when the car rounds a curve. If only a single gyroscope were used, this would tend to make the car tip in opposite directions, according to whether the car is going forward or backward, and the tip might be dangerous in going about a curve, as Mr. Brennan found to his cost in his earlier experiments. But when the two gyroscopes revolving in opposite directions are linked together, the action of one

balances that of the other, and their joint effect is always to make the car lean in at a curve, which is precisely what it should do to ensure safety. Moreover, the two linked gyroscopes keep their planes of revolution parallel to the rail, as is essential to their proper action, and as a single gyroscope would not do.

The balancing action of the gyroscope seems no whit less remarkable after it is explained. It should be said, however, that the force exerted by the mechanism is not so tremendous as might at first thought appear, for the gyroscopes are by no means called upon to counteract the entire force of gravity brought to bear on the car. They do not in any sense *lift* the car; they only balance its two sides, which when left to themselves are approximately of equal weight. The car, as a whole, weighs down on the track just as heavily with the gyroscopes in action as when they are still. Balancing is a very different feat from lifting, as every one is aware from personal experience. Two men pushing against the opposite sides of a monorail-car could keep it balanced on the central rail tho its weight vastly exceeded anything they could lift.

THE EVOLUTION OF AN IDEA

It goes without saying that so elaborate a mechanism as Mr. Brennan's gyroscope was not perfected in a day. Neither was it hit upon by accident. It belongs in the category of inventions that were thought out to meet a mechanical need. Mr. Brennan is an Irishman by birth, but he was taken by his parents to Australia at the

age of nine and remained there throughout the years of his early manhood. Observation of the condition of the roads in Australia and of the enormous retardation of development due to inadequate transportation facilities led him to ponder over the possibilities of improvement in this direction, as he was jolted about the country in a coach with leather straps in lieu of springs. It became clear to him that a way must be found to build railroads more cheaply. Furthermore, it was brought to his attention through observation of the condition of the cattle that were shipped from North Australia across the continent, that a railway car that would enable the cattle to make the journey in comfort, and thus arrive in marketable condition, would have enormous value for this purpose alone.

For years, Mr. Brennan tells me, the problem haunted him of how to make a monorail-car balance itself. He studied the action of rope-walkers, and he attempted various crude methods of balancing a car, which all came to nothing. He thought about the possibility of using the gyroscope, and even purchased several elaborate gyrostats in order to study gyroscopic action. As a friend of Sir Henry Bessemer, he knew of that gentleman's experiments with the gyroscope in attempting to make a steady room in a ship, but these also availed him nothing. It was not until he purchased the toy top at Cannes, as already mentioned, that he got hold of a really viable idea; and then, of course, almost numberless experiments were necessary before an apparatus was devised that could meet all the requirements.

At last, however, a model car, more than fulfilling all his fondest hopes, was in actual operation. It remained to build a car of commercial size. To aid him in thus completing his experiments, Mr. Brennan received a grant of $30,000 from the India Society. He believed that a car one hundred feet long and sixteen feet wide would be balanced by gyroscopes three and a half feet in diameter so effectively that it would stand erect and rigid tho fifty passengers were clustered on one side of its spacious room.

The accuracy of this prediction was put to the test in November, 1909, when Mr. Brennan exhibited the first gyrocar of commercial size. The result was demonstrative and convincing. The large car, carrying forty or fifty passengers, operated exactly as its inventor had foretold, and the doubts of the most skeptical were set at rest. Photographs of the car in actual operation, with its load of passengers, were sent broadcast, and it became apparent that the introduction of the gyrocar in competition with railway-, trolley-, and motor-cars of the old type would be only a matter of time.

When we come thus to consider the gyrocar as a vehicle in which all of us may soon have an opportunity to ride, there is one practical question that is sure to present itself to the mind of almost every reader. What will be the effect should the electrical power that drives the gyroscopes give out at a critical moment, as, for instance, when the car is just crossing a gorge or river on a cable? Mr. Brennan's ingenuity has anticipated this emergency. The gyroscopes that balance his cars operate in a

vacuum, and all the bearings are so well devised as to give very little friction. The wheels will continue running for a considerable time after the power is shut off. The large gyroscopes of the commercial car, it is estimated, will perhaps require two hours to attain the highest rate of rotation, but they will then continue revolving at an effective speed for some hours, even if no further power is applied to them.

It may be said, too, that the gyrocar is provided with lateral legs that may be let down in case of emergency or when the car is not in use, to avoid waste of energy in needless running of the gyroscope. All in all, it would appear that the dangers of travel in a gyrocar should be fewer than those that attend an ordinary double-track car; and Mr. Brennan believes that it will be possible, with the aid of the new mechanism, to attain a speed of one hundred and fifty, perhaps even two hundred miles, an hour with safety.

VIII

THE GYROSCOPE AND OCEAN TRAVEL

It must not be supposed that Mr. Louis Brennan's remarkable monorail-car affords the first illustration of an attempt to make practical use of the principles of gyroscopic action. The fact is quite otherwise. The idea of giving steadiness to such instruments as telescopes and compasses on shipboard with the aid of gyroscopes originated half a century ago, and was put into fairly successful operation by Professor Piazzi Smyth (in 1856). More than a century earlier than that (in 1744), an effort was made to aid the navigator, by the use of a spinning-top with a polished upper surface, to give an artificial horizon at sea, that observations might be made when the actual horizon was hidden by clouds or fog. The inventor himself, Serson by name, was sent out by the British Admiralty to test the apparatus, and was lost in the wreck of the ship *Victory*. His top seemed not to have commended itself to his compatriots, but it has been in use more or less ever since, particularly among French navigators.

BESSEMER'S COSTLY EXPERIMENT

The first attempts to use the gyroscope at sea were of a technical character, and could have no great popular interest. But about twenty-five years ago an attempt was made to utilize the

principle of the spinning-top in a way that would directly concern the personal comfort of a large number of voyagers. It was nothing less than the effort to give stability to a room on a steamship, in order that the fortunate occupant might avoid the evils of seasickness. The man who stood sponsor for the idea, and who expended sums variously estimated at from fifty thousand to more than a million dollars in the futile attempt to carry it into execution, was the famous Sir Henry Bessemer, famed for his revolutionary innovations in the steel industry. It would appear that Bessemer's first intention was to make a movable room to be balanced by mechanisms worked by hand. But after his project was under way his attention was called to the possibility of utilizing gyroscopic forces to the same end. As the story goes, he chanced to purchase a top for sixpence, and that small beginning led him ultimately to expend more than a million dollars in playing with larger tops. His expensive toy passed into history as the "Bessemer chamber." It was actually constructed on a Channel steamer; but the would-be inventor, practical engineer tho he was, did not find a way properly to apply the principle, and his experiment ended in utter failure.

With this, the idea that the gyroscope-wheel could ever aid in steadying a ship at sea seemed to be proved a mere vagary unworthy the attention of engineers. But not all experimenters were disheartened, and since the day of Sir Henry Bessemer's fiasco a number of workers have given thought to the problem—with the object, however, of applying the powers of the

revolving-wheel not merely to a single room but to an entire ship. I have personal knowledge of at least one inventor, quite unknown to fame, who believed that he had solved the problem, but who died before he could put his invention to a practical test. It remained for a German engineer, Dr. Otto Schlick, to put before the world, first as a theory and then as a demonstration, the practical utility of the revolving-wheel in preventing a ship from rolling.

DR. SCHLICK'S SUCCESSFUL EXPERIMENT

In the year 1904, Dr. Schlick elaborated his theory before the Society of Naval Architects in London. His paper aroused much interest in technical circles, but most of his hearers believed that it represented a theory that would never be made a tangible reality. Fortunately, however, Dr. Schlick was enabled to make a practical test, by constructing a wheel and installing it on a small ship—a torpedo-boat called the *Sea-bear*, discarded from the German navy. The vessel is one hundred and sixteen feet in length and of a little over fifty-six tons' displacement. The device employed consists of a fly-wheel one meter in diameter, weighing just over eleven hundred pounds and operated by a turbine mechanism capable of giving it a maximum velocity of sixteen hundred revolutions per minute. This powerful fly-wheel was installed in the hull of the *Sea-bear* on a vertical axis, whereas the Brennan gyroscope operates on a horizontal axis. So installed, the Schlick gyroscope does not interfere in the least with the steering or with

the ordinary progression of the ship. Its sole design is to prevent the ship from rolling.

The expectations of its inventor were fully realized. On a certain day in July, 1906, with a sea so rough that the ship rolled through an arc of thirty degrees, when the balance-wheel was not in revolution, the arc of rolling was reduced to one degree when the great top was set spinning and its secondary bearings released. In other words, it practically abolished the rolling motion of the craft, causing its decks to remain substantially level, while the ship as a whole heaved up and down with the waves. These remarkable results, with more in kind, were recorded in the paper which Sir William White read before the Institution of Naval Architects in London in April, 1907. He himself had witnessed tests of the Schlick gyroscope, and, in common with his colleagues, he accepted the demonstrations as unequivocal.

Fully to understand the action of Dr. Schlick's invention, one must know that it is not a mere wheel on the single pivot, but a wheel adjusted in such a fashion that it can oscillate longitudinally while revolving on its vertical axis. In other words, it is precisely as if one of the two gyroscope-wheels used in the Brennan car (greatly enlarged) were so placed that its main axis was vertical, its secondary axis, or axis of oscillation, being horizontal and at right angles to the ship's length. Thus, while spinning on its vertical axis the body of the top is able to oscillate, pendulum-like, lengthwise of the ship.

In principle the action of this wheel is not different from that of an ordinary top on your

table which wabbles to the right or to the left when you push its axis straight away from you. Yet to the untechnical observer it seems as if the Schlick gyroscope were a living thing, governed by almost human motives. If you apply a brake to prevent the longitudinal oscillations of the gyroscope, the effect, even though the flywheel still revolves at full speed, is precisely as if you pinioned the arms of a strong man, so that he saw the futility of resistance and made no struggle to free himself. Under such circumstances the gyroscope—tho it continues to spin as hard as ever—has no effect whatever in preventing the rolling of the ship; it stands there, like the strong man bound, expressing its discontent with an angry groan.

But if you release the brake so that the entire mechanism is free to oscillate lengthwise of the ship, all is changed. It is as if you cut the cords that bound the strong man's arms. Instantly the mechanism springs into action. It will no longer allow itself to be swung with each roll of the ship; it will resist and prove which is master. Its mighty mass, pivoted on the lateral trunnions, lunges forward and backward with terrific force, as if it would tear loose from its bearings and dash the entire ship into pieces. It causes the ship to pitch a trifle fore and aft as it does so; but meantime its axis stands rigidly erect in the lateral plane, tho the waves push against the sides of the ship as before. The decks of the vessel, that were tipping from side to side, so that loose objects slid from one rail to the other, are now held rigidly at a level, scarcely permitted to deviate to the extent of a

violent tremor. The gyroscope has won the contest. To maintain its victory it must continue its backward and forward plunging; but from side to side its axis will not swerve.

DID GYROSCOPIC ACTION WRECK THE "VIPER"?

It was the failure to understand that a gyroscope-wheel, to work effectively, must be given opportunity to oscillate in this secondary fashion that led Sir Henry Bessemer to spend an enormous sum in a vain effort to accomplish on a small scale what Dr. Schlick's gyroscope accomplishes for the entire ship. Now it is clearly understood that a marine gyroscope on an absolutely fixt shaft can not exercise its full action; but there is still a good deal of difference of opinion among engineers as to just how much a spinning body must be permitted to oscillate in order to make its gyroscopic effects noticeable. The discussion that has taken place over the loss of the torpedo-boat *Viper* furnishes a case in point.

Some critics contend that the loss of the boat was due to the gyroscopic action of its turbine engines. They believed that the turbine at the stern of the little ship held that portion of the craft in a rigid plane, while the anterior portion of the ship, caught in the trough of a wave, broke away. That the ship broke in two is certain; but competent engineers have denied that gyroscopic turbines could have had any share in its destruction. According to their view, the turbines of a ship are powerless to exert the gyroscopic action in question, because

their axis are fixt and they thus have not the opportunity for secondary oscillation to which I have referred. Meanwhile there are other equally competent mechanicians who believe that the vibration or oscillation of the body of the ship itself may suffice, under certain circumstances, to give the turbine precisely such freedom of motion as will enable it to exercise a powerful gyroscopic effect. Dr. Schlick himself contends, and seems with the aid of models to demonstrate, that such a gyroscopic action is exercised by the wheels of a side-wheel steamer, which revolve on a shaft no less fixt than that of a turbine. If such is the case, there would seem to be no reason why a turbine-engine may not at times exercise the power of a tremendous gyroscope, such as it obviously constitutes. The question must find practical solution at the hands of the naval architects of the immediate future, as turbine engines are now in use in several of the largest steamships afloat, and others are being installed in craft of all descriptions.

THEORETICAL DANGERS OF THE GYROSCOPE

It should be said that engineers disagree as to the practical utility of the Schlick gyroscope. No one questions that it steadies the ship, but some critics think that its use may not be unattended with danger. It has been suggested that under certain circumstances—for example, the sudden disturbance of equilibrium due to a tremendous wave—the gyroscope might increase the oscillation of the ship to a dangerous extent, *tho* ordinarily having the opposite effect. It

is believed that a good many aeroplane fatalities have been due to the gyroscopic action of the propeller, particularly when equipped with the rotating Gnome motor.

The danger from this source in the case of the ship is probably remote. There is, however, another danger that can not be overlooked, and which marine architects must take into constant account. What we have already seen has made it clear that the revolving wheel of the Schlick gyroscope, to be effective, must bear an appreciable relation to the mass of the entire ship. Such a weight, revolving at a terrific speed and oscillating like a tremendous pendulum, obviously represents an enormous store of energy. It was estimated by Professor Lambert that a gyroscope of sufficient size to render even a Channel steamer stable would represent energy equal to fifty thousand foot-pounds—making it comparable, therefore, to an enormous projectile. Should such a gyroscope in action break loose from its trunnions, it would go through the ship with all the devastating effect of a monster cannon-ball.

The possibility of such a catastrophe is perhaps the one thing that will cause naval architects to go slowly in the adoption of the new device. We can hardly suppose that the difficulties represented are insuperable, but undoubtedly a long series of experiments will be necessary before the Schlick gyroscope will come into general use. The apparatus has been tested, however, on a German coast steamer. It may not be very long before craft of the size of Channel steamers and boats that go to Cuba and the Bermudas are equipped with the device.

Naturally enough, this prospect excites the liveliest popular interest. Visions of pleasant ocean voyages come before the mind's eye of many a voyager who hitherto has dreaded the sea. It remains to be seen whether the expectation is destined to be realized.

But whatever the future of the gyroscope as applied to pleasure-craft, there would seem to be little doubt about its possible utility as applied to vessels of war. It may fairly be expected that battle-ships will be supplied with this mechanism in the not distant future—unless, indeed, the perfected air-ship should render the battle-ship obsolete. Amid the maze of engines of destruction on war-vessels, one more would not appal the builder; while the advantage of being able to fling a storm of projectiles from a stable deck must be inestimable.

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